# DEVELOPMENT OF A SOIL BASED FLOORING MATERIAL FOR TROPICS

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Degree of Doctor of Philosophy in Civil Engineering

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## Declaration of Candidate and Supervisor

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| | |
|---|---|
| Prof. R. U. Halwatura | Prof. A. H. L. R. Nilmini |
| Department of Civil Engineering | Faculty of Technology |
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## Abstract

The unplanned and rapid growth of developments has led to adverse impacts on the climate and biodiversity. Among them, the building industry is one of the foremost sectors. Therefore, the proper selection of building materials and techniques is of prime importance. Out of several sustainable materials, the soil has gained more attraction due to its advantageous features. Hence, this century has seen several notable milestones after passing thousands of years with the usage of soil in construction. Earthen flooring is one aesthetically attractive building element that has recently been restored and modernized. In fact, terrazzo, ceramic tiles woods, etc. are the widely available flooring materials associated with certain undesirable features. Hence, a necessity has arisen to seek alternative flooring materials. However, soil as a flooring material has not been investigated properly. Therefore, this research focuses on developing soil as a flooring material with sustainable features while pursuing possible means of increasing the strength of soil as a flooring material and enhancing the top surface finish. Then, the durability and service characteristics, cost benefits, thermal performance would be evaluated with the behavior on a real scale. The optimum soil gradation was first investigated. Next, investigation results showed that the increase in water content causes a decrease in the compressive strength, linearly at a constant rate for all cement percentages. The selected soil cement mix with water form a concrete and 150 mm standard cubes were used to determine the compressive strength. The best size and shape of test specimens were predicted and the relationship between compressive strength and specimen size and shape was identified in this background. Consequently, soil concrete was tested with the addition of metal as a course aggregate, but it did not influence the improvement of compressive strength in a significant level. Soil concrete with chemical admixtures showed that the admixtures were useful to enhance the workability and strength. The Mixed proportion consisted of fine particle contents 0-10%, a sand content 55%-60%, gravel content 30%-35% with a maximum gravel size of 25mm. The required cement was 18%-20% that depended on the usage of the admixture. The required moisture range was 16%-19% for soil concrete without admixtures to achieve a workable mix. To form the top surface to be architecturally attractive and for smoothness with regard to user comfort, the surfaces were smoothened in this background. Among several resins, one synthetic resin and floor sealer were selected and applied on the prepared soil floor samples as a surface coating. The Phenol-formaldehyde (novolac) resin was selected and cured with the Hexamethylenetetramine (HMTA) with heat treatment. The bonding capacity of coating in the soil floor, the water absorption, the abrasion resistance, the slip resistance and the stain resistance were analyzed according to the relevant standards to evaluate the soil floor with the resin coating for durability and service characteristics. Though all the tested parameters were within the standard requirements, the abrasion resistance of resin surface failed in this context. However, the floors which were with floor sealers showed positive results. At the end of the series of experiments, the mixing proportion, the top surface finishing material and the method of construction were decided for the continuation of the research. Thermal performance and cost benefits were then evaluated and compared with other selected existing floorings. According to the temperature variation pattern, the soil floor showed a significantly low top surface temperature compared to the other floorings and indoor air temperature. In fact, the Life Cycle Cost (LCC) for soil floor is significantly less compared to other existing floorings.

Finally, the study findings suggest that soil could be used as a flooring material and a floor sealer could be used as a top surface finishing layer with a long-term sustainability. However, further research is required to find the suitability for a building's upper floors and the use of natural resin as a top surface finishing material.

**Keywords:** soil-based construction, soil concrete, sustainable flooring materials, self-compacting in-situ cast floor

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# CHAPTER 1 : INTRODUCTION

## 1.1. General

Despite animals, who attempt a poise with nature to sustain their lives, human beings have been only concerned with the instant fulfilment of their ‘‘desires,", In fact, this has resulted in the depletion and destruction of the ecosystem of which they are dependent. Interestingly, in the recent decades, several countries around the world have undergone significant population growth resulting in housing shortages and increased demand for infrastructure. As a result, millions of new and upgraded buildings and infrastructure services will be needed to support this rapidly growing metropolitan population. Therefore, currently, continuous unplanned development has being carried out with unlimited needs which has led to a progressive unpleasant effect on the environment and ecosystem. Among them, the building industry is one of the most important and dynamic areas where development has broadened in an unprecedented manner. In terms of the environment, the construction sector produces a higher percentage of carbon dioxide emissions and uses resources than any other commercial operation, signifying an unacceptable conditions. In addition, a probable rise in the global population and their demands in terms of housing and other infrastructure facilities have further increased these effects [1], [2]. Therefore, as the demand grows, it is critical to consider the use of more environmentally friendly building materials and processes, which will greatly add to the construction industry's eco-efficiency and, thus, to a more sustainable development.

However, certain nations do not prioritize the aspects of sustainability. As poverty levels differ from country to country due to financial constraints, as well as a lack of support, the local circumstance should play an important role in developing effective construction options considering features such as the environment, land conditions, financial availability, local building expertise, and the aspects in which local stakeholders could be involved. However, materials such as steel, cement, and concrete etc are common in the current construction industry that is not manufactured sustainably. The processing and transportation of these products cause significant environmental issues, including a high level of greenhouse gas emissions. Nonetheless, locally manufactured construction materials are available which do not create significant environmental pollution while providing local jobs, promoting local craftsmanship, and making them fully renewable. Bamboo and timber, as well as earth and adobe blocks, are examples of such sustainable construction materials. Soil is precisely an environmentally sustainable resource as it has a low embodied energy for its production process and zero embodied energy for being the raw material soil and only soil [3]. Therefore, suitable earth technologies have been used in many countries including Sri Lanka. However, the use of such construction materials is currently rare in high-density urban environments, as people usually do not use such materials due to shortage of availability. Hence, the building with costly and unsustainable materials has been widely accepted due to the availability of these materials. Thus, further research is required to assess the suitability of these materials, as well as to develop and popularize them among the general public in urban areas, where the majority of the world's population will reside in the future.

The natural material- 'soil/mud' has been used in the building construction for thousands of years. Many researchers around the world, including Sri Lanka, have been working on various projects involving soil as a construction material [4],[5],[6]. As opposed to building and techniques using traditional materials, earth architecture has an environmental benefit which makes it highly efficient. Earth is abundant and ubiquitous. In addition, economic benefits, waste generation, energy depletion, carbon dioxide emission, contamination, and indoor air eminence are all positive facets of earth building.

Earth building includes wattle and daub, cob, rammed earth, earth bricks (adobe), and compressed earth blocks (CEB). Moreover, the earthen floor is a centuries-old flooring practice that has recently been resurrected and updated. The concept of living on an earthen floor is not new; humans have done so for thousands of years. Earthen floors are made of locally available natural materials which include sand, clay, and water. Traditional earthen floors are usually the bare soil underneath the building, tamped down with human feet and watered regularly to keep dust at bay. Durable and comfortable buildings were built using soil, sand, rocks and plant fibers, that would stand for generations. These same materials were used to add smooth, attractive finishes, providing bright, beautiful and durable interiors also. People have lived in houses made from materials found nearby for a considerable amount of time in human history. These ancient rituals are still practiced in many parts of the world today [7].

However, when determining the environmental effect of the construction material, it has to be viewed in terms of raw material degradation, accumulated energy use, global warming, acidification, tropospheric ozone formation, stratospheric ozone depletion, eutrophication, waste output, and human health. Though earth constructions have more benefits against environmental aspects, there are several drawbacks related to earth construction such as less durability, structural limitation, and high maintenance. As a solution to these drawbacks of earth construction and to overcome the unfavorable effect in cement concrete, mud concrete was innovated. Mud concrete is a result of series of experiments and with several extraordinary characters and also use in different ways such as MCP, MCWB, in-situ cast wall systems already [8], [9], [10], [5].

Further, global warming has turned into an unending problem. Climate change is caused by global warming and is causing increasing discomfort in many regions. Extreme energy consumption in the process of non-natural cooling or heating is linked to global warming in the field of architecture to convert the building comfortable. Many researchers have attempted to pursue experiments in order to discover a cozy building that does not use devices (air conditioners or room heaters) to make thermal comfort in the room. Building thermal production is closely linked to a region's temperature conditions. Air coolers were needed in regions with comparatively hot temperatures, while room heaters were required in regions with cold temperatures. In the study of thermal comfortability, energy consumption becomes the most important factor [11]. Hence, the proper selection of construction materials in any part of a building will thereby significantly affect any comfortable construction [12], [13], [14] [15].

As a result, this century has seen a number of notable milestones in sustainable architecture, such as the production of construction materials that have less negative environmental impacts, lower demand for non-renewable energy, while maintaining optimal user-friendliness and comfortability.

### 1.2. Research Gap

Material selection for construction is a critical constituent towards more sustainable construction in sustainable development. Therefore, one of the most critical challenges for sector leaders is to identify alternative sustainable materials and technologies to overcome harmful consequences in the existing building sector.

Multiple aspects must be considered when choosing a building material, including the impact on occupant health, protection, aesthetics, durability, maintenance, and costs. Budget limitations also restrict material choices, but they could also be determined by manufacturer details, personal knowledge, or the product's initial expense[16]. Among several building construction materials, flooring is one of the most used materials. Cement, terrazzo, ceramic tile, marble tile, and wood are more widely available flooring materials worldwide, including Sri Lanka. Due to factors such as high production costs, high energy demand, and negative impacts on the atmosphere and human health, it has become necessary to seek out alternative flooring products in order to mitigate these negative effects and find new material of long-term sustainability.

Further, there are several researches that have been pursued to invent sustainable construction materials to the industry in the recent past. Among them, the earth/soil used as construction material in any part of the building has been an interesting area. However, soil used as a floor finishing material has not been investigated completely. Furthermore, the newly invented mud concrete is used for wall and paving construction, there are no studies done to determine soil concrete as a flooring material. Hence, further studies are required to understand the possibility to use soil as a flooring material and to implement soil-based floor construction materials in the industry.

Therefore, this research is focused on developing a soil-based flooring material with sustainable features.

### 1.3. Aim and Objectives

The main aim of this research is to develop a sustainable flooring material based on soil and a few more sub-objectives which includes,

1. Finding the possible means of increasing the strength of soil as a floor finishing material

2. Finding a suitable mix and the thickness for the soil-based floor finish.

3. Discovering a suitable top surface finish.

4. Evaluating durability and service characteristics

5. Evaluating the long term performance with respect to its cost benefits

### 1.4. Methodology

1. Identify sustainable construction and materials through the literature review, the use of soil as a construction material, available floor finishing materials via their properties, construction methods, and applications, etc; with respect to sustainable construction.

2. Cast test samples with different ratios of soil: cement (/or alternative stabilizer/adhesive): and carry out a series of experiments to identify the best mix proportions.

3. Evaluate the possibility of introducing a resin as a floor finishing layer. For this, a suitable resin will be identified and its bond characteristics with mud concrete flooring evaluated.

4. Evaluate the durability and service characteristics of the proposed floor.

5. Analyze the thermal performance and user perfection on s concrete floor and comparing with a few commonly available floorings

6. Calculate the life cycle cost and comparing it with the available flooring materials.

The flow diagram for the overall study program is shown in Figure 1-1

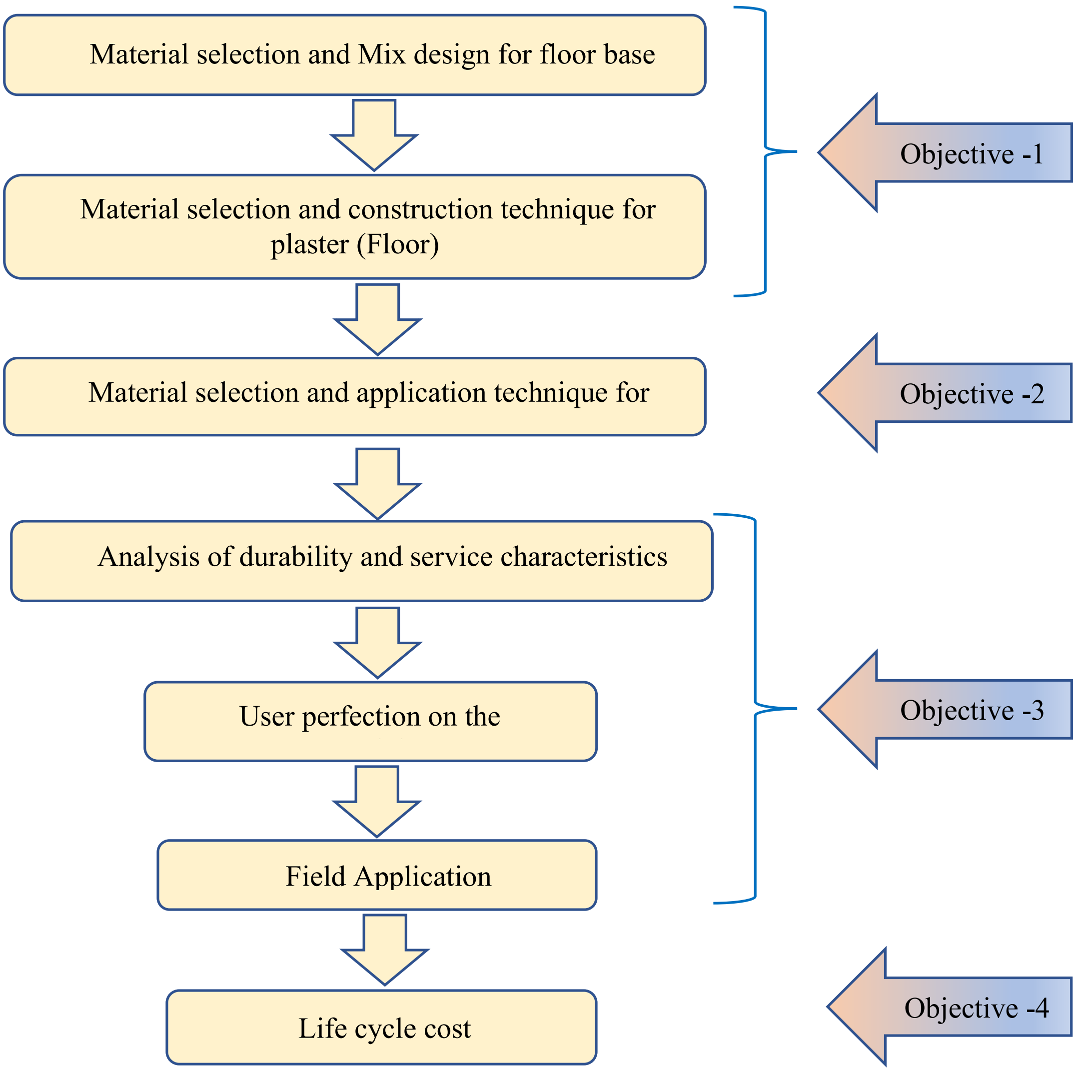



*Figure 1-1: The flow diagram for the overall study program*

## 1.5. Main Findings

1. The water requirement for self-compacting soil concrete was identified as 16% -19% by dry soil weight determine with the aid of the floor table tests. The optimum fine particle (0.075mm < fine < 0.425 mm) content was found to be 5%-10% that the strength decreases with the water content showing linear variation. This linear variation for all the cement content considered is with a constant gradient. Thus y= mx +c type of relationship was developed for variation of strength with the water content of soil concrete.

2. More than 50% of 28 days' strength is achieved in the first 7 to 10 days and with time, strength variation shows slow increment and as cement concrete this soil concrete also shows the maximum strength at 28 days. When considering the strength variation with cement percentage it was identified that raising the cement percentage beyond 16% to 18% has little discernible influence on compressive strength. The samples of 16% cement have the highest strength. Also, increases in cement percentage do not have a major impact on the strength of soil concrete.

3. Both the drying shrinkage and wetting expansion became zero at 28 days the water content percentages but the shrinkage was higher for soil concrete which has a high water percentage.

4. Chemical admixture could be used to enhance the soil concrete properties at different levels of the admixture. The use of admixture reduces the quantity of cement used in soil, improving environmental and economic sustainability. However, there is an optimum dosage of admixture for cost-effective usage.

5. The top surface could be finished with a floor sealer which enhances the service and durability characteristics of flooring material.

6. The temperature of the soil floor was lower than the temperature of other floor surfaces and the temperature of the indoor air.

7. The Life Cycle Cost is much less for soil concrete compared to the other common materials.

### 1.6. Organization of the Thesis

The breakdown of the chapters in this thesis is as follows;

- Chapter 01 discussed general information about the research background and gap, research objectives, and methodology. Main findings which were concluded after the research was also discussed.

- Chapter 02 presents a detailed review of literature conducted to find out the background of the research through sustainable construction and materials, existing floor finishing materials.

- Chapter 03 presents the mix design development for soil flooring. This chapter elaborates the results of optimum usable gravel range, optimum gravel: sand: fine ratio and optimum water-cement ratio. In addition, the sample size and shape effect on the test results and the possibility to use alternative course aggregate for soil concrete also was discussed.

- Chapter 04 presents the behaviour of soil concrete with chemical admixtures.

- Chapter 05 presents the development of top surface coating.

- Chapter 06 presents the real scale behaviour of proposed flooring and cost-benefit analysis

- Chapter 07 of the dissertation presents the conclusion/recommendations and future works related to this research.

# CHAPTER 2 : LITERATURE REVIEW

## 2.1. General

The previous chapter included context evidence for the research, including a thorough description of the study's purpose and objectives. In addition, the methodology to overcome the objectives was described. The focus of this research was on a novel approach to produce a flooring material using soil. Accordingly, a systematic literature review was conducted as a strategy. The evidence and data gathered during this study served as the starting point for all of the measures involved in incorporating a new soil-based flooring material with a long-term sustainability. Therefore, the literature review was conducted under the following topics.

- Sustainable construction and materials
- Construction materials for thermal comfort in a tropical climate
- Earth/Soil as a construction material
- Use of admixtures in concrete
- Mud concrete
- Existing floor finishing materials
- Available floor coatings and resins

## 2.2. Sustainable construction and materials

Each type of business practice has a direct and an indirect effect on the environment despite , the world's corporations paying minimal attention to the environmental behaviours of their operations, as well as their own long-term viability [17]. The word "sustainability" has then been an unavoidable problem for all sectors, including the construction industry.

There are many definitions used worldwide to define sustainability and among them, the most recognised description of sustainable development is " meeting the needs of the present without compromising the ability of the future generations to meet their own needs” [18]. The importance of enforcing sustainable development is critical, as “what we create today will stream the building environment of tomorrow and will affect future generation’s capacity to fulfil their needs” [19].

### 2.2.1. Sustainable construction

Many leading environmental activists interpreted the term "sustainability" in the context of the climate. In 1990, Norway's prime minister said that sustainability means "leaving ample opportunities for future generations to enjoy a quality of life comparable to ours." The term "sustainable development" was used in legal papers as a global aim to be achieved. In 1994, the First World Conference for Sustainable Architecture was held in Tampa, Florida, where the future of construction in terms of sustainability was seriously debated [20]. Sustainable construction is a subset of sustainable development that relates to the building trade and is described as "development and responsible maintenance of a sustainable built environment based on resource-efficient and ecological values" [21]. Though sustainable construction is a new concept for the civil engineering and construction industry, this concerns over environmental pollution dating back to the ancient times [20].

Several attempts were made during the first World Conference on Sustainable Building to describe sustainable construction in several aspects such as minimizing resource use, maximizing resource reuse, use of renewable or recyclable materials, protecting the natural ecosystem, providing a stable, non-toxic environment, and pursuing quality in the built environment. These standard aspects effectively articulate the spirit of what engineering and the construction industry could do in the face of global environmental issues [17].

Since the built environment creates impacts on all human activities, the building sector as a whole must promptly come to an understanding of the wider environmental and social plan posed by the principle of sustainable development [22],[20]. Since all human operations face significant environmental problems, it is important to pay keen attention to this topic because of conventional construction and architecture practices that are not pursued as well as the opportunity of our era that will not be retained into the next century and beyond [17].

The building industry involves producers and suppliers of construction materials, employers, builders, architects, and eventually end-users of facilities. The industry's conventional approach has focused on the assumption that advances and gaining economic growth while meeting expectations and wishes of customers, as this sector is critical to a country's economic and social growth [23]. However, the industry has had a significant impact on the environment of a civilisation, along with transportation and manufacturing processes, because it accounts for roughly 40% of global gross energy consumption and related Green House Gas (GHG) emissions. As a result, it has increased the pressure on the building and development industry to solve environmental distresses [24]. Most of the attention on this topic is on reducing energy usage and related GHG emissions from the built environment's activity which is most significant. However, the processes used to create the built environment have gained less consideration from environmentalists because their environmental effects are considered to be minimal concerning those generated by the activity of the built environment [25]. However, building processes are major business practices that require a significant amount of energy and capital as opposed to other manufacturing processes [24].

At present, natural materials, different sources of energy, and water are all used extensively in construction. Each year, building construction absorbs 40% of all raw stone, gravel, and sand used globally, as well as 25% of all virgin timber. Further, extraction, transportation, and processing of raw materials have often resulted in resource degradation and destruction of biological diversity. Additionally, buildings use 40% of the electricity and 16% of the water used globally in each year. Further, buildings use 30% - 40% of principal energy in their production, operation, and maintenance, and are responsible for 40% of global warming gas emissions worldwide. These behaviours have obvious negative consequences [26], [27].

The usage of energy and associated pollution, the use of raw materials and waste disposal, and the use of water and land are all examples of environmental impacts produced by the construction process. Energy consumption and emissions are the most important of these issues since they are inextricably tied to global warming and the loss of non-renewable energy resources. Further, energy consumption produces emissions that contribute to global warming and acid rain. In addition, wastes produced during the construction process often pollute the air and water, posing significant health and safety risks [20]. Nevertheless, in terms of energy use and resulting pollutants, the transition of building methods toward environmentally friendly activities is in its early stages [23]. The first point to consider is that the significance of environmental impacts from construction processes has been underestimated due to several factors such as the dispersed nature of construction processes which employ a vast number of subcontractors with difficulties in making accurate quantification of environmental impacts. Furthermore, the complexities of building methods, as well as the uniqueness of each project and the high degree of variation, make it almost difficult for organizations to create continuous processes [28]. In recent years, the building industry, like other sectors, has been under deep pressure to embrace environmentally sustainable practices. However, environmental sustainability is now regarded as a crucial competitive advantage.

Primarily, sustainable architecture includes three major dimensions as social, economic, and environmental, as opposed to the traditional perspective, which prioritized economy, utility, and longevity. The social factor deals with topics related to improving people's quality of life. The economic dimension tackles concerns such as employment growth, increased competition, lower operating/maintenance costs, a high-quality working culture that leads to increased efficiency while the environmental factor is concerned with approaches to architecture, construction, operation/maintenance, and deconstruction that reduce negative environmental impacts such as air pollution, waste discharges, water supply usage, and land use [29].

The importance of the construction industry for sustainability is a global concern. The challenges confronting developing nations are immense and much more dynamic than those confronting the developed world. Low incomes, insufficient education and health care, a scarcity of skilled human resources, and plenty of other problems afflict developing nations while the most fundamental human needs are still often unfulfilled, in comparison to the developed countries, where these needs are often met [30]. Further, there are significant differences between the two worlds in terms of skill levels, strategies, building industry capability, and institutional capacity. As a result, it is expected that the huge majority of available resources are devoted to solving the most basic issues in developing countries. Developing countries continue to view urban development challenges from a technical perspective due to their immense technological advances. However, D. Baloi [23] mention that technical advancements alone are insufficient, and that science and technology would not be able to correct all previous mistakes and pave new paths into the future. Apart from technological advances, developed countries must address people's perceptions and choices as the key enablers for long-term development, as they are the product of a people-cantered approach to sustainability. Sustainable construction arrives with a slew of challenges and opportunities. At the root of these challenges and opportunities is the need to strike a balance between the key sustainability aspects of financial, social, and environmental issues. According to Y. Miyatake [17], all stakeholders must understand that achieving sustainable development requires a change in the built environment's processes. That is, the building industry must improve the way it performs in construction operations, promoting recycling, material reuse, and energy and natural resource management. The construction industry should be able to achieve an acceptable balance between environmental and economic efficiency. For this reason, there are many methodologies, approaches, and methods available, such as Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) [31]. Therefore, the implementation of environmental policy results in two kinds of benefits. First, the materials protect through reuse, recycling, and the conversion of waste into valuable forms. Then, revenue through improved working conditions, the reduction of costs associated with discharges, and decreased energy consumption during the production process.

On the other hand, there are several significant obstacles to achieving sustainability. First, construction output has been declining in developed countries; secondly, output in developing countries has been progressively increasing. As a result, it could be recognized that achieving sustainability in these countries is extremely difficult; and third, the construction sector is dependent on the implementation of sustainability measures from other sectors of the economy, such as agriculture [31].

However, by contemplating these sustainability factors, building materials play the most important role in sustainable construction, beginning with the mining of raw materials and continuing through life cycles. As a result, the available building materials and their manufacturing technologies were investigated in order to determine the characteristics of sustainable materials and manufacturing technologies.

### 2.2.2. Sustainable construction materials

Sustainable building materials are the materials that are cost effective, and socially acceptable and that minimize harmful environmental effects during the production and construction of buildings today and in the future [32]. The choice of construction materials is more significant because, the total cost of most structures, the energy uses of any building, and even the adaptability of certain buildings by society greatly depends on the type of materials used. According to [33], [29] construction materials and methodologies applied in a building , there would be a great influence on sustainable development issues and this makes construction materials an important factor in sustainable development.

Sustainable architecture makes use of existing natural resources and depends on environmentally friendly materials [34]. In order to put construction material studies in the sense of sustainable development, it is important to define the measures for sustainable construction materials. H. Danso [29] analyzed the general and relevant metrics for determining the sustainability of building materials. However, data on the most relevant sustainability metrics in relation to building materials is lacking [32]. The respondents chose twelve (12) important indicators for assessing sustainable construction materials from a list of twenty-five (25) indicators acceptable from the literature. Human toxicity, climate change, and solid waste are three essential environmental metrics for determining sustainable construction materials. Furthermore, the four main social metrics for sustainable building materials were defined as adaptability, thermal comfort, local capital, and housing for all. In addition, the five primary economic metrics for computing sustainable building materials were discovered to be maintenance expense, operating cost, initial cost, long-term savings, and life cycle. They have further recommended that these twelve metrics be used in future studies aimed at determining the sustainability of building materials [32].

Recently, Scholtz et.al, [30] state that the supply of sustainable construction materials is increasing, thanks to new technologies and the procurement of materials that are environmentally friendly and built to improve building energy efficiency. Wool bricks, solar tiles, sustainable concrete, paper insulation, and triple-glazed windows are the few among the sustainable construction materials listed by [35]. Earth-based technology such as rammed earth, compressed earth blocks, and stabilized soil blocks are widely used renewable building materials in low-income societies. A series of researches on earth-based sustainable building materials have been studied. Among them H. Danso et.al., [36] conducted a study of the current literature on the impact of stabilizers (fibres and binders) on the technical efficiency of soil blocks or bricks using compressive strength, water absorption, and flexural strength. M.J.C. Delgodo & I.C. Guerrero [37] investigated at the circumstances of compressed earth block use in new a project, and manuals that might be used as national reference documents. S.M.Hejazi et.al., [38] saws the background, advantages, applications, and potential management issues associated with using various forms of natural and/or synthetic fibres in soil reinforcement G.Giuffrida [39] viewed at national standards, materials, structural planning, architecture, quality management, foundations, and repair for rammed earth construction. The environmental advantages associated with earth building were studied by F.Pacheco & SaidJalali [2], including an analysis of its historical and current applications, economic challenges, non-renewable resource usage, waste productions, electricity usage, carbon dioxide emissions, and indoor air quality etc.

In the last decade, the use of waste in the production of renewable building materials has piqued researchers' attention. The properties of renewable building materials made from waste in concrete or blocks have been studied in depth. The properties of sustainable concrete with waste materials like paper, plastic, and natural fibers have been studied in several experiments. There has been a considerable amount of testing done on earth-based building materials. Though rammed earth has had a variety of studies done on its properties, earth/soil blocks/bricks have had a large amount of research done on them also using various waste materials such as natural fibers, sawdust, scrap tire rubber, plastics, and animal wool fibers. All of these findings add to the body of knowledge on environmentally friendly building materials [40], [41] [42], [43], [44], [45], [46]. Despite the introduction of many new building materials with sustainability characteristics, energy use in urban environment activities is rising day by day. As a result, when choosing building materials, it is essential to understand not just the production process of the materials, but also the energy required to create a comfortable built environment. As a result, when choosing building materials, it is critical to understand the climatic conditions in the region. As a consequence, the impact of building materials on thermal comfort in a tropical environment will be examined in the following section.

### 2.2.3. Construction materials for thermal comfort in a tropical climate

Buildings are major energy consumers in all nations, particularly in countries with extreme climatic conditions, and they consume a significant amount of energy to heat and cool them. Although there are many ways to minimize the heat and air conditioning load in buildings, one of the most critical is to carefully plan and choose the building envelope and its components. Computers and lighting requirements have increased the building's thermal loads, necessitating the introduction of air conditioning units to offset these demands and offer a safe interior thermal environment [47].

Thermal comfort is described by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 55 as "the state of mind that communicates satisfaction with the thermal environment" [48]. Many factors affect thermal comfort such as air temperature, radiant temperature, humidity, air circulation, metabolic rate or human activity, clothes [49].

Low blood pressure, salt imbalance, fainting or reduced mental capacity, weakness, dehydration by sweating, and even death are all symptoms or illnesses that may be aggravated or influenced by a hot indoor thermal environment at work [50]. The effects of hot working conditions on the working community have been recorded in various research around the world [47]. The ability of office occupants to adjust to thermal equilibrium, physical, mental, and behavioural patterns is referred to as their well-being in a certain environment for a certain climate [51]. Heat stress is a greater challenge in tropical and warmer climates in terms of thermal comfort and heat-related deaths and illnesses [47].

Many workplaces have mounted mechanical equipment such as air conditioners, fans, and different types of cooling devices to counterbalance the hot working atmosphere and give thermal relief to staff. These devices are energy-consuming, expensive to repair, and operate solely on electricity [51].

Thermal discomfort can be caused by buildings on their own. If this is not addressed during the design phase, the problem of thermal comfort may become expensive to address afterwards. A positive approach to energy efficiency and thermal comfort, which can be observed in the materials chosen to build the structures, is still controversial and not generally adopted. During the development phase, the use of environmentally friendly and low thermally conductive building materials for living spaces/workplaces will give a long-term solution to the issue of heat stress caused by environment change [52].

The thought of green buildings has arisen in recent years, with the primary goal of using environmentally sustainable materials and reducing resource consumption, reducing electricity demand, and is gaining traction in the western world. Traditional expertise of the use of environmentally friendly and thermally tolerant construction materials has been passed down through generations in developed countries and tropical regions. However, for a variety of reasons, many workplaces have been unable to embrace the methods as a solution to the problem of thermal comfort [53].

Minimizing the cooling demand of the living room is one way to gain thermal comfort while reducing energy consumption. The use of construction materials as a passive strategy in tropical countries with limited resources and energy supply would be an inexpensive and simple way to monitor and increase thermal comfort. To achieve thermal comfort, several materials with passive cooling properties may be used. This may be an adaptation technique that provides a long-term approach to the problem of rising temperatures and their effect on the living spaces' thermal comfort. Natural materials with inherent thermal insulation capabilities from the outside environment, modern materials with high insulation capabilities, reflective paints, and green roofs are all examples of building envelope materials. Researchers investigated properties for specific that could provide thermal comfort to residents, including materials that have been in use for decades, eco-friendly materials, and modern emerging technology materials, with the belief that adequate insulation is required to reduce the thermal impact of radiation from the sun.

Various researchers have suggested that the thermal output of advanced materials plays a key role in energy conservation and thermal comfort. Therefore, to achieve the required thermal comfort without losing structural stability, a mixture of natural and synthetic construction materials is frequently used. However, when changing the composition and using a combination of natural and synthetic materials, keep in mind that the features of the materials used must be based on the building's intended application as well as the weather conditions in order to ensure optimum thermal comfort [54]. The interior temperature, and hence the thermal comfort of the building's occupants, is also affected by mutual radiation between the wall and the ceiling [47]. Natural construction materials have been used since the dawn of time, and building materials manufactured with natural ingredients have their own range of benefits and drawbacks in today's built world, including problems with load-bearing capability and longevity. In fact ,thermal conductivities of a wide variety of traditional and natural materials are ideal for use in buildings to provide optimum thermal comfort [53].

The thermo-physical properties of construction materials, building alignment, airflow, building room use, and the combination of modern and passive energy conservation technology all affect a building's thermal comfort. The building shell acts as a barrier not only to the outside but also to climatic elements that specifically influence the system. Internal thermal comfort is determined by the characteristics of the construction materials used, which are influenced by temperature and humidity outside [55].

Traditional materials have greater thermal conductivities and diffusivities than modern materials, resulting in inefficient and unpleasant heat transport [53]. Bamboo, timber, grass, linoleum, crushed earth block, rammed earth, cement, vermiculite, flax linen, sisal, sea grass, cork, extended clay grains, coconut, wood fibre plates, and other eco-friendly construction materials are all renewable materials and reduce energy consumption inside buildings [56],[57]. Marble, concrete, and asphalt are excellent heat conductors that can be avoided in exterior building, while materials that carry the least amount of heat from outside to inside, such as some types of glass, and wood, should be used for walls, floors, and windows to provide a comfortable interior [58].

Wood and timber are considered to be strong thermal insulators and are ideal for a number of applications such as windows, doors, roofing, and flooring [59]. Wood's thermal properties are a result of moisture content and wood type since it is a hygroscopic fiber. The way wood is handled and how it is used is primarily determined by its intended use in construction and the environment of the region. Wood products such as fiber board and hardboard panels built from fibers have lower thermal conductivity values than real hardwood due to the large number of air gaps in the fiber based panel [47].

Straw has been used as a building material for many years because it is biodegradable and has no environmental impact. The use of straw has been a common technology in Mexico, France, Finland, and Australia due to the combination of the high isolative nature of the bales and the thermal mass given by the thick plaster covering of the interiors. A well-constructed straw-bale building has excellent thermal efficiency. In fact , straw is a thermally tolerant fiber with a thermal resistance rating of 6.51 to 7.82 W/m2 K for a 55 cm thick straw bale which can be the most effective insulators [60]. Interestingly, plastered straw-bale construction is used in load-bearing and in-fill straw-bale construction to produce long-lasting, super-insulated buildings that have thermal comfort. In tropical climates, straw-bale buildings perform better thermally than other materials used for walls, but they have inherent drawbacks such as less bulk to retain heat in the building fabric and poor load bearing properties, rendering them unsuitable for taller structures [48].

One of the most significant heat-resistant construction components is the bricks [61]. Despite exterior diurnal changes, inside temperatures in red brick structures remained relatively stable, making it an excellent alternative for building material, especially in hot areas. According to studies H. Binici et.al., [62] Mud brick reinforced with fiber (FRB), retains the indoor temperature lower throughout the summer [62]. Buildings constructed with FAB work better thermally and have a cooler indoor atmosphere than those constructed with clay bricks [63]. In a simulation conducted by Alahabad et al., it was discovered that indigenous materials have greater thermal properties than typical building materials [64].

Thermal comfort has a major impact on the fitness, psychology, and competitiveness of the workforce, which is the backbone of every economy. The use of construction materials as a passive mechanism for enhancing thermal comfort within the buildings in hot and humid climates is vital, with an emphasis on the factors that make these building materials more suited to delivering thermal comfort to the indoor environment. However, in low income environments, the use of locally abundant materials, with due regard for reliability, ease of maintenance, and expense, will be the most required consideration other than the properties of building materials.

New building material technologies that provide energy efficiency and thermal comfort are expected to gain popularity, and efforts to incorporate new building material solutions are needed to shield potential populations from the threats of thermal stress presented by the projected increase in temperatures due to climate change. Among these many sustainable materials to improve the thermal comfortability inside the building, the earth is identified as the most effective one. Therefore, a considerable amount of research has been carried out to improve the earth as a construction material which is used from ancient stage.

### 2.2.4. Earth/Soil as a construction material

A combination of clay, silt, sand and bigger aggregates such as gravel or stones are referred to as "earth" by a scientific name. Clay with microscopic attractive particles serves as a binder, keeping the sand and gravel particles in the soil mixture composed. The raw material for earth construction is often collected directly from the construction site when excavating for foundations or basements at a depth of 1.0 m -1.5 m [65]. Depending on the extraction source, the soil will represent different concentrations and forms of clay, silt, sand, and gravel. As a result, the actual output of the construction could vary from site to site, and the mix preparation for a given application too. The life cycle of construction material with soil/earth is shown in Figure 2.1[65].

There is no consensus about when man first started using earthen architecture. According to evidence in the literature, earth constructions may have been in operation for over 10,000 years. It is not a stretch to imagine that earthwork began between 12,000 and 7000 BC, with the arrival of early farming societies [66].

There are several examples of earth structures that were constructed 1000 years ago that have survived into the twenty-first century, such as the Great Wall of China, which started construction about 3000 years ago, and the Horyuji Temple in Japan has rammed earth walls built 1300 years ago and Eleven (11) storied earth buildings in the Further, the most common earthen buildings in Spain were adobe and rammed earth walls, preceded by wattle and daub walls. Spanish earth architecture history can be seen in a wide range of structures, from rich and poor homes, secondary edifices in rusticzones, and some monumental earthen structures. Also, the Murallas de Niebla in Huelva are an excellent example. It's a 1600 m long rammed-earth wall built in the mid-twentieth century [37]. Table 2.1 summarized the few cases to know how old is the earth's construction.


*Figure 2-1: Life cycle of earthen construction [65]*

*Table 2-1: Historical data for earth construction*

| | Date | Description | Source |
|---|---|---|---|
| 1 | Over 9000 years | Adobe earth block | [69] |
| 2 | Period of EI-Obeid in Mesopotamia (5000-4000 BC) | Use of earth for construction | [70] |
| 3 | 8000-6000 BC | Adobe earth block | [70] |
| 4 | Dated back to 7500 BC | Oldest Adobe block | [71] |
| 5 | 3000 years ago | The Great wall of China build on rammed earth | [71],[68] |
| 6 | 814 BC | Phoenicians in the Mediterranean basin | |
| 7 | 1300 years ago | The rammed earth temple in Japan (Horyuji Temple) | |
| 8 | 1000-1500 AC | The village of Taos in New Mexico | |

Earth construction includes numerous techniques such as wattle and daub, cob, rammed earth, adobe, and compressed earth blocks (CEB), and Table 2.2 summarizes some earth construction techniques.

*Table 2-2: Earthen construction techniques and production methods*

| | Techniques | Method | Source |
|---|---|---|---|
| 1 | Wattle & daub | Earth is compacted against a woven lattice of wooden strips | [72] |
| 2 | Cob | Earth mixed with straw and water to have a masonry wall as layer by a layer | [73] |
| 3 | Rammed earth | Compaction of earth mix with water (stabilized or not) inside the formwork | [74] |
| 4 | Adobe | Filling the wooden mold with moist earth to form a block and sundry | [74] |
| 5 | Plasters | Finely graded clay | [65] |

The soil is compacted against a woven lattice of wooden strips in the wattle and daub process, which has been consumed for nearly 6000 years. The Portuguese technique of ‘‘tabique" is similar to wattle and daub in several ways. The cob procedure includes adding soil, straw, and water to create layer-by-layer masonry walls [75], [76].

Rammed earth is the process of compacting wet earth (stabilized or not) within a wooden or steel formwork. Recently, a composite earthen wall structure that includes rammed earth, cob and wattle, and daub has been used [2].

Most ancient buildings were constructed with adobe because it is a very basic earth-building technique [77]. The method of producing adobe bricks involves filling wooden moulds with wet soil and drying them in the sun. Since shrinkage cracks could occur on the surface of the adobe as it dries, some researchers recommend using straw or some other vegetable fiber to avoid this. However, this perspective is not universal, as vegetable fiber may emerge from fungi [78], [79].

By compressing the earth within a mould with a special unit, the CEB represents the development of adobe bricks. The application of pressure may be done by hand or by using a machine. Since the earth's hardness is closer to that of rammed earth, earth blocks can be made which is heavier and more resistant than adobe bricks [80].

While earthen architecture has been used since the beginning, as shown by the thousands of buildings scattered across the globe, it was abandoned with the advent and obsession with modern materials such as concrete, bricks, and steel, especially in the most industrialized countries. However, in less developed nations, it has never ceased being used, even though people choose other materials because the soil is associated with suffering in their minds. However, at present, there is a reintroduction in earth construction due to being a material that has very slight embodied energy [81] [3], [37].

Currently, technical research is focused on construction methods and materials that have a lower environmental effect than current building materials such as concrete and fired clay. Thus, earth has resurfaced as a viable and realistic choice. The globe is now being rediscovered all over the world for its biodiversity and potential to provide a high degree of comfort in an indoor climate [65].

Nearly 50% of the world's residents live in earth-based residences currently and the majority of these earthen structures are found in developing countries, but also in Germany, France, and the United Kingdom, where over 500,000 people live in earthen structures. As a result of a sustainable development initiative, earth construction has increased significantly in the United States, Brazil, and Australia [82].

With the demands of earthen construction, there is a need for building professionals, architects, engineers, and artisans to be trained and encourage the use of earthen construction where ever possible. However, with the drastic variation of properties of soil from point to point on the earth, each new project should have an explanation for the field of soil through a particular analysis [3]. Civil engineers could easily carry out the required soil analysis through simple field tests and/or laboratory tests to provide reliability and suitability as well. However, earth construction faces many difficulties because earth buildings are out of the common construction rule in many countries [1],[39]. Though several countries commenced professional training on earthen construction as well as courses that discuss expertise in this area earth construction does not depend only on training. It is necessary to have specific regulations and standards. However, the general appropriateness of soil compositions for a building is not standardized due to its inherent natural variability from place to place on the earth, which strictly depends on the environmental conditions [83], [3]. Nevertheless, several countries have issued codes related to the rammed earth and adobe, there are several other earth building methods such as wattle and daub, cob, and compressed earth blocks. Table 2.3 summarized some codes and standards available in the current earth constructions used in different countries.

Earth/soil is twice sufficient as an environmentally sustainable substance because it has small embodied energy for its processing technique and less embodied energy when using unstabilized earth as a raw material [3]. However, the soil cannot be used for construction due to some properties, but soil properties could be improved by stabilization. Soil stabilization changes the mechanical and physical characteristics of soil by adding some chemicals or physical additives through the decrease of soil plasticity, improving its workability, etc [89]. However, all soil cannot be stabilized and, soil can be used for appropriate stabilization if its compressive strength more than 2 MPa [89].

Many scholarly data are available to find different kinds of chemical, physical & mineral additives used as soil stabilizers to improve soil properties as construction materials. They are summarized in Table 2.4.

The use of cement for soil stabilization enhances embodied energy despite the fact that earth building has a lower embodied energy, emits less carbon dioxide, and generates less trash. The use of gypsum instead of Portland cement for soil stabilization is substantially better cost-effective [95].

*Table 2-3: Available codes and standard related to earth construction*

| | Code/ Standard | Year of publication | Source |
|---|---|---|---|
| 1 | 1st earth building code – German | 1994 practice only up to 1998 | [66] |
| 2 | 1st specific regulation on earth construction " Bulletin 5" - Australia | 1995 revised on 1976,1981,1987,&1992 | [84] |
| 3 | Australian Earth building handbook | 2002 | |
| 4 | Specification for rammed earth and adobe - Spanish | 1992 | [85] |
| 5 | Regulation for rammed earth and adobe- New Mexico | 1991 | [86] |
| 6 | NZS 4298:1998, NZS 4298:1998, NZS 4299:1998 – New Zealand | 1998 | |
| 7 | France REEF DTC 2001, REEF DTC 2101, REEF DTC 2102 | 1945 | [65] |
| 8 | India , IS 1725 | 1960 | |
| 9 | Code of practice for rammed earth structures | 2001 | [87] |
| 10 | SPECIFICATION FOR COMPRESSED STABILIZED EARTH BLOCKS – SLS 1382 : | 2009 | [88] |

*Table 2-4: Different types of soil stabilizer*

| Type of stabilizer | Description | Source |
|---|---|---|
| Molasses cow-dung, sawdust | For Adobe brick | [90] |
| Straw fiber | For Adobe brick, reduces the compressive strength | [91] |
| Polysaccharide, Sugger | High strength and high durability | [92] |
| Cement, Lime, Resin | Not economic, Resin is eight times more expensive than the use of cement. | [93] |
| Fly ash | Increase the workability of the soil mixture and as well as deducting moisture content can increase the compressive strength | [94] |

The rising global demand for energy is a significant contributor to our world's unsustainable development. Energy consumption should have increased by 40% between 2007 and 2030. The progression in energy demand is attributed to two major factors: an increase in global population and an increase in electricity usage by the people [96].

The use of native materials as it occurs with earth construction requires less energy. This is because, earth mining typically contains the disposal of the top layer, which is a low-energy operation that could be completed manually. This is very dissimilar from the removal of raw materials required for old-style masonry building materials. The reason is, there is no pollution related to the transportation of soil for earth construction since it is usually situated directly underneath the organic deposit of the soil and the soil located nearby at the construction site, since the traditional materials such as concrete, ceramic, tiles, and cement blocks, etc., which are often transported from far away from construction sites [97].

Many scholars agreed that adobe buildings could decrease CO2 pollution by about 100 tons a year [98], [99], [100] due to less cement content about in the range of 6–8%. The embodied energy in cement stabilized rammed earth walls raises with cement content linearly in the range of 0.4–0.5 $GJ/m^3$ [101]. Furthermore, compressed stabilized earth blocks are more environmentally approachable than fired bricks, as they require 15 times less energy and pollute the atmosphere eight times less [102].

Furthermore, earth building wastes could be easily discarded at the point of mining, posing no environmental risks. And if the soil has been stabilized by adding cement and/or lime it could be reused, thus so earth construction hardly creates any waste [98].

There is more scholarly evidence showing that earth buildings are more thermally comfortable and comply with required building regulations in their countries regarding thermal requirements [103], [104]. Thermal insulation is not the most simulating character of earth buildings but its high thermal inertia, i.e., the capability to accumulate and be able to manage the heat. Though there are many advantages in earth construction concerning sustainability, few weaknesses could be identified as less durable compared to traditional construction materials, labour-intensive, structural restrictions, need great maintenance [105].

Earth construction is labour-intensive, thus the manufacturing and construction costs are the most significant factors in certain countries with high labour costs. Therefore, materials used in earth building do not affect the final cost in such countries. However, in fewer developed countries, with affordable labour force at a relatively low rate, this is not a vital factor. The cost-effectiveness of the stabilization process, the type, and quantity of the binder used is the determining factor for these countries [2], [106], [105].

Moreover, even though our forefathers lived in buildings made out of natural resources that were free of toxics, in today's residential buildings, indoor air is highly polluted due to high levels of substances and heavy metals used due to build in synthetic materials. As a result, it causes to many health causes such as asthma, skin frustrations or rashes, nose and throat irritation, headaches, birth defects and cancer [107]. The hostile properties of indoor air volatile organic compounds (VOCs) are not associated with earth construction, so inhabitants of these structures have better indoor air quality [108]. An extra benefit of earth buildings' interior air quality is their ability to regulate relative humidity [109], [110],[71].

Considering the drawbacks such as less durability, require high maintenance, mud concrete is newly innovated to overcome these drawbacks of earth construction. Mud concrete is an upgrade of soil to make building construction materials with several extraordinary characteristics.

### 2.2.5. Mud concrete

Due to its strength and toughness, cement concrete has become the most common building material today. However, in terms of environmental protection, it has become a major concern. As a result, producing new building materials has become essential in order to hold the construction industry afloat. Accordingly, substantial research has been undertaken to establish soil as an enduring construction material [9],[66],[111],[112]. Among them, mud-concrete is a recent invention that was created after a sequence of tests at the University of Moratuwa in Sri Lanka. It is concrete made out of earth/soil stabilized with cement [113],[114], [5]. Mud-concrete could be used in a variety of ways in construction. The first effort was to create masonry wall blocks, supplemented by pedestrian paving blocks and a mud-concrete in-situ cast load bearing walling system. A combination of Fine 10% (sieve size 0.425 mm), Sand 55% -60% (sieve size 0.425 mm sand 4.75 mm), Gravel 30% - 35% (sieve size 4.75 mm gravel 20 mm), and water 18% to 20% from the dry mix was concluded as precise mix proportions for mud concrete. The amount of cement used to stabilize the soil for mud concrete is determined by the final product's strength requirements. Mud concrete construction has a number of unique characteristics. One of the most important characteristics of mud concrete is self-compaction [115]. The mud concrete mix could flow inside a formwork and compress with its own weight without any external effort if it had this consistency. Thus, mud concrete contributes to the development of a low cost, energy efficient, labour saving, well-finished production technique. Researchers realized that the soil compositions play a significant role as the key component when considering the mix design.

Fine and coarse aggregates account for 60 to 75 percent of the cement concrete volume (70 to 85 percent by mass) and have a substantial effect on the freshly mixed and hardened materials, mixture proportions, and cost. Coarse aggregates are made up of one or more types of gravel or crushed stone with particles that are often larger than 5.00 mm and range in size from 9.50 mm to 37.50 mm [116]. Natural sand or crushed stone and most fragments smaller than 5.00 mm make up fine aggregates (0.2 in). The principle of mud- concrete technology replaces sand and metal in concrete with fine and coarse aggregates in soil. By changing the particle sizes of soil, the intended roles of sand and metal could be achieved. Similar to cement concrete technology, the structure, form, and scale of aggregate could affect the workability, longevity, strength, weight, and shrinkage of mud concrete [115]. Therefore, the production process of mud concrete commenced with the sieve analysis according to the 'Unified Soil Classification System' ASTM D 2487 [18]. ASTM D 2487 classified any soil as 75 mm >Gravel > 4.75 mm, 4.75 mm >Sand> 0.425mm, 0.425 mm > Fine > 0.075 mm [117].

The exact gravel percentage governs the strength of the material [115]. However, in the wall and paving blocks, the gravel ranges that can be used in mud-concrete are restricted. Since the blocks are thin, there is not enough room for coarse gravel (big particle sizes). When particle sizes become larger, the volume of gravel included in a block can no longer retain sufficient proportions, resulting in high porosity and as a result, the block's compressive strength will suffer. Therefore, the mixture of the mud concrete block could only use fine gravel ranges (4.75 mm ≤ gravel ≤ 20 mm) in soil [115], [5]. The result of the experimental series, [118] found that generally 4.75 mm to 50 mm is the gravel range available in the native gravelly laterite soil. The mud concrete strength increases with the gravel size but the optimum gravel size is in the range of 4.75mm – 32mm range which gives the maximum compressive strength for in-situ walling system. Since the walling structure could extend vertically, it would be able to create more space for both fine and coarse gravel in the mix. F.R.Arooz et.al, and C.Udawatta et.al., [115], [5] concluded that the usable gravel range for mud concrete construction is restricted to 35% - 55% sand which is limited to 60% - 40% in-situ casting system. Also, the growing the gravel fraction does not necessarily result in increased mud concrete compressive strength. The particle size distribution of formed soil will determine its compressive strength. As a result, the mud concrete researchers came to the conclusion that the optimal gravel size, gravel: sand ratio, and continuous particle size distribution provide soil particles to create a packed soil structure with limited voids with improvements on the mud concrete's compressive strength [115].

As a result of a series of experiments on mud concrete, special emphasis has been placed. Mud concrete has a number of advantages, including the ability to slightly modify the soil to provide a concrete which is durable. The use of gravel as a strengthening agent where clay and cement are used as the binder, and the use of a high water/cement ratio will reduce strength, but this water content can allow the mix to flow freely, allowing it to compact itself. Furthermore, the excess water in the mix can provide a porous structure that can later be used to cool the house, providing greater thermal relief than other earth-based construction techniques. Since there is no burning, the block can be cast to any size to meet the available structural and architectural equipment and consumer specifications [9].

Mud concrete, on the other hand, is an environmentally friendly construction material because it uses less cement than concrete. Hence it could be considered as a sustainable building material [119], [120]. While cement is used in small amounts to reinforce the soil, it makes mud concrete low costly and friendly to the environment. After being less costly than metals and other materials, ordinary Portland cement (OPC) processing has a host of environmental concerns. The calcination of limestone and the combustion of fossil fuels emit more than one ton of carbon dioxide per ton of OPC emitted during the manufacturing process. As a result, researchers  found that other materials, such as fly ash, could be used instead of cement [113],[114]. Fly ash has several advantages as a stabilizer for mud concrete over cement such as minimizing carbon dioxide emission (1 ton Portland cement emit 0.82 tons $CO_2$ but 1-ton fly ash emits 0.027 tons $CO_2$ ),and reducing the usage of natural resources (Portland cement consist of many virgin resources such as limestone, clay, and shell), low heat of hydration of cement, low cost than cement,  improves workability, reduce shrinkage, leach of metal is reduced in to environment by using fly ash instead of going to the land fill [94]. Finally, mud concrete products have acquired a patent under Sri Lankan intellectual property act No.36 of 2003 from the international patent classification. Mud concrete block," Patent No: 17616 and, "Mud paving block," Patent No: 17724

However, further research is needed to enhance soil's suitability for use as a building material by improving soil properties such as strength, hardness, and sustainability. The properties of cement concrete are being improved day by day by applying additives or mechanical ingredients. As a result, defining such an element and evaluating the probability of using it in soil is critical. However, these data also reveal a knowledge deficit.

## 2.3. Admixtures in the construction industry

Some of the properties of construction materials can be changed by combining an appropriate additive and some admixtures. The concrete industry upgrades to overcome day-to-day issues with time, and the use of mineral and chemical admixtures has become a miracle finding in this regard. Chemical admixtures are essentially water reducer (plasticizer), set retarders and accelerators, classified as Type A, B, C in ASTM C 494-92 and similar in BS 5075 part 1: 1982. Water reducers (plasticizers) are usually used to achieve higher strength with the water/cement ratio while maintaining the same workability of concrete without admixture, to retain the same workability by reducing the cement, and to improve workability. The admixture classified as type A for only water reducer, Type B as a set retarder, Type C as an accelerator, Type D to both water reducer & Set retarder, Type E for both water reducer & accelerator, Type F as high range water reducer and Type G as High range water reducer and set retarding. The Type D, E and F are considered as superplasticizers according to ASTM C 494-92 [121]. The most significant upgrading in concrete technology during the last 30 years has been the use of superplasticizers. Because the superplasticizers have the ability to ensure much more important improvements than any other chemical admixtures [122]. Superplasticizers which is different from plasticizer chemically is a comparatively recent type and improved variant of plasticizers produced in Japan and Germany in the 1960s and 1970s, respectively [123]. These admixtures, particularly superplasticizers, are mixed into the cement to give the properties that are high-quality concrete requires.

The superplasticizers are high-range water reducers that are used to ensure that cement particles in a concrete suspension are properly dispersed [124]. The quantity of required water due to the usage of admixtures differs from 5% to 15% but it depends on the type of cement, aggregate and air entering agent (if any). The use of superplasticizers may reduce water to the extent of up to 30% without dropping the workability in difference to the possible reduction of up to 15%in the case of plasticizers [123]. If the admixture is used correctly, the durability also can be improved [125]. Normally superplasticizers are used to produced flowing concrete as floor or pavement slabs and also to the production of very high strength using normal workability with a very low water-cement ratio. The increases the workability at a given water/cement ratio, typically rising the slump from 75mm – 200mm. The high workability is measured by the flow table test and value between 500-600 mm. The resultant concrete is cohesive and not subjected to excessive bleeding or segregation. When the aim is to achieve high strength at given workability, the use of a superplasticizer can result in a water reduction of 25-35% compared with the normal water reducer [125]. The addition of a superplasticizer can decrease the water-cement ratio of concrete to 0.25 to 0.30 without influencing its strength or workability. This also increases the concrete's durability. Thus, at low water-cement ratios, a homogeneous workable concrete that is less susceptible to bleeding and segregation can be obtained [126].

Once a superplasticizer is used to reduce water with specified workability, it strengthens the properties of hardened concrete and, enhances strength and toughness because of the decrease of capillary porosity and permeability, all of which are attributed to a lower water-cement ratio (w/c). An alternative approach to employ superplasticizers is to minimize both water and cement such that the concrete with superplasticizers has the same workability and strength as the control concrete without admixture. Since superplasticizers work as cement reducers in this situation, they can lower the heat of hydration, which is beneficial for concrete in hot climates or large buildings. The higher aggregate/cement ratio, which is attributed to the drop of cement content and the rise in aggregate compensating for the volume decrease of cement and water, also has a positive impact on shrinkage and creep elimination. Furthermore, adding superplasticizers without changing the water or cement content increases the workability of concrete [127]. Superplasticizers will improve the settlement features of concrete mixtures by enhancing the workability at a given w/c. Therefore, superplasticizers enhance the placement of concrete mixtures even with low w/c as essential for strength or durability reasons. An intimate of superplasticizers based on acrylic polymers is existing with improved placing characteristics. The mix design of self-compacted concrete is based on the trial and error method, it is vital to find the optimum dose of Superplasticizer in order to lessen the trials and labour. The use of a superplasticizer which is called High Range Water Reducers (HRWR) is practiced for the production of flowing, self-leveling, and self-compacting for making high strength and high-performance concrete. Self-Compacted Concrete (SCC) is a highly workable concrete of high strength and performance that can flow under its own weight without segregation or bleeding through restricted areas. Reduce the volume ratio of aggregate to cementitious content, increase paste volume, and use multiple viscosity-enhancing admixtures and superplasticizers to achieve SCC. It has been discovered that the fluidity of concrete is not enhanced to the same degree for all types of cement by all superplasticizers. Some superplasticizers could provide a higher fluidizing effect on some type of cement than other types of cement. Giving a particular superplasticizer and cement the best fluidizing effect is a complex process involving many variables such as cement structure, fineness, and other factors. About the complexity of the compatibility problem, it can be solved in part by using a quick and ready field solution. Basic field tests like the Marsh cone test and the Mini slump test are also beneficial. Flow table testing is often used to assess the best superplasticizer dose for the cement [123].

Today, the most significant advancement in the cement industry is the expanded usage of mineral admixtures to substitute a portion of cement in order to eliminate carbon dioxide pollution, lower cement prices, and improve technical efficiency. High-performance concretes with a low W/C ratio enable the use of appropriate and compliant superplasticizers in conjunction with the new cement, which can convert high-consistency concrete into concrete with great workability. When using superplasticizers in concrete, some types of cement can cause issues such as cement–superplasticizer incompatibility, slump irregularity, and quick workability loss. The primary method to combat this negative effort is to select the most effective combination of cement–superplasticizer, allowing to find a maximum water reduction, good workability, and satisfactory rheology throughout the placement and the finishing concrete [122].

Any mineral admixtures, such as blast furnace slag, fly ash, silica fume, or natural pozzolan, may improve the cementitious materials' contact with superplasticizers.

[128] verified that superplasticizer adsorption is influenced by the volume of $C_3A$ in the cement as well as the existence of soluble alkali sulphates [129], [130]. Several researchers have suggested that calculating the flow time of grout can be used to investigate cement–superplasticizer compatibility [131].

The chemical admixture is not uniformly adsorbed on cement particles depend on the type of cement mineral. As an example, the alite and belite provide less adsorbed, whereas $C_3A$, $C_4AF$, and free CaO are even more adsorbed [132].

These days, as a result of the market obtainability of various kinds of admixtures and cement, there is flexibility in choosing the right concrete composition giving to the chosen parameters, taking into account the overall economy and the safety of the environment. Admixtures are regularly developed of admixtures, particularly new superplasticizers, which dramatically alter the properties of the concrete. However, if there is an incompatibility between the cement and the admixture, in addition to economic losses, it can cause a quick loss of operability, extreme quickening/retardation of setting, and low rates of strength gain [126].

### 2.4. Floor finishing materials

The decision to select a given product as a floor finishing material in a particular building is not only mean that this material must exhibit a set of appropriate technical characteristics to predicted service conditions but is also require these characteristics to remain unchanging for a service lifetime[133]. Floors are more liable to impact damage than walls, because of falling objects and the point-load characteristics of some footwear. There are common causes to damage the floor. Some of them are impact damage due to voids under the floor finishes, damage from moving heavy loads across floors [134]. Hence, floor finishes are expected to withstand impact loads and abrasion without breaking or losing their surface texture [135]. The problem of selecting a flooring material by considering these criteria is that these criteria are not being a key characteristic of the material, but depending directly on the conditions and wear mechanisms to which the material is subjected [133]. Therefore when predicting the durability of flooring materials, it should consider the perfect condition such as setting conditions (interior or exterior) volume and kind of traffic (pedestrian or vehicular) presence of external agents (abrasives, water, chemical products) [133]. Floor finishes in a building are normally used for decorative, protection, and aesthetic purposes also [136].

Consequently, material selection for flooring is a crucial constituent of sustainable design and construction as other construction materials. The decisions of selection are based on several factors. Material properties, production procedure, cost, and effects on human health via indoor air quality are a few of them. However, environmental impact is becoming a more important and common practice, intending to minimize negative environmental impacts. However, still measuring and comparison of environmental impact for various building materials is relatively challenging due to complexity [137].

Many different floor finishing materials are used all over the world. Some of them come from a previous epoch, while others despise recently. In terms of sustainability, all have advantages and disadvantages. Venetian building workers invented terrazzo, which is one of the most popular flooring materials. This style of the floor is now used in both high-end and low-cost structures all over the world. This is a form of mosaic flooring in which chips are embedded in a matrix and polished. To obtain a smooth finish, the terrazzo is poured in place, cured, ground, and polished. The chip is the ingredient that acts as an aggregate that is screened to various sizes. Small pieces of marble, granite, quartz, quartzite, and river gravel were used and at present, onyx, glass, small tile, or synthetic types were used as chips. The matrix, which was made of mortar cementitious, modified-cementitious, or resinous content, serves as a binder to keep the chips in place. The use of the terrazzo upgraded over the years and after few centuries it was used indoors as high-grade flooring, for its aesthetic and decorative characteristics, a wide range of colours, designs, and shapes; ranging from bright, to bold, to classic architectural styles. It is extremely hard wearing that it could durable than almost other types of hard floorings. Terrazzo is highly favoured, because it is easy to clean and maintain. Further, it has no organic solvent components, thus there are no toxic vapours or exposures to harmful chemicals. It has also higher slip resistance compared to other flooring materials. The unit weight of terrazzo usually varies from 3.2 $kN/m^2$ to 4.5 $kN/m^2$, based on the layers that make up the terrazzo and how it is constructed. The terrazzo is much heavier than all other non-load-bearing floor elements, as well as any other building component. A disadvantage of terrazzo floor is that after the initial heavy polishing is required in the initial stage and it is essential to polish the floor time to time to maintain the shine and appearance of the floors [138],[139], [140], [141].

Ceramic materials, such as crystals and rocks, have historically been used in the building industry as inorganic, non-metallic materials. They're made from a normal raw material blend that includes silica, argillaceous minerals, and alkaline oxides. Based on the mixture with high consistency and performance, the final ceramic products may have a number of characteristics, such as porosity, texture, and the appearance of enamel, among others. Furthermore, the ceramic industrial industry continues to grow in order to lower prices, improve product reproducibility, and achieve a greater understanding of ceramic properties and evolution [142]. Porcelain tiles come in a variety of designs to satisfy a variety of decorative and personal preferences. Due to its fine, solid, and complex characteristics, this is one of the best tiles for use on the floor. Porcelain tiles are available in a variety of colours, including glazed, unglazed, and polished. Its rock-solid action and ability to survive an unwavering environment [143].

Unglazed, double-fired glazed, and single-fired glazed ceramic tiles are the three types of flooring ceramic tiles available. They are made in three different ways, depending on how much glaze is used and how many firing cycles are used [144]. However, ceramic tile manufacturing makes the greatest contribution to environmental impact [145].

Wood is still widely used in architecture around the world. While wood is an excellent building material, it is not always available locally. Transportation costs must be factored in, as well as the cost of replanting trees in the region where the timber was cut. Only if trees are replanted will the use of wood as a construction material be considered environmentally friendly [146].

### 2.4.1. Floor finishes with waste materials

The rise in the quantity of solid waste generated by industrial, mining, domestic, and agricultural operations has been attributed to population growth, growing urbanization, and rising living standards as a result of technical advances [147], [148]. Recently, several agencies and investigators have been seeking to achieve the privilege of reusing waste in environmentally and economically viable forms [149].

All of these ground-breaking efforts have been with the use of solid wastes in building materials. Among such construction waste, crumpled clay brick and roof tile could also be recycled and reused to dispose them in an environmentally friendly way. Any clay brick and roof tile are shattered in the factory during processing and transportation and are instantly crushed in the factory. The use of crushed bricks and roof tiles to produce recycled concrete for building construction is one way to reuse them. According to the research, concrete made of crushed clay bricks and roof tiles has better mechanical, thermal, and fire resistance properties, with the properties differing depending on the brick and tile form used. This literature has stated that this waste could only be used for low-performance concrete, like pavement blocks [150], [151] [152], [153]. With this data I. Milicevic et.al., [154] produced floor blocks with crushed clay bricks and tile. According to their findings, it is possible to replace natural aggregate with crushed brick and tile in 50 % fine and 75% coarse proportions and obtain the necessary properties of the concrete floor block which satisfied the minimum requirements of the standards. Additionally, improved concrete floor blocks are more thermally efficient than conventional natural aggregate units [154].

In an attempt to eliminate solid waste in the form of eggshells and plastic as construction raw materials, floor building tiles have been created. According to the observations, the inclusion of eggshells has little effect on compressive strength or water absorption, but the inclusion of plastics tends to increase abrasion resistance. Plastic has a tendency to minimize tile compressive strength. As a consequence, they should be used with care [135].

Vieira et al. [155] used salvage wastes from the rock industry to render tiles and flooring in 1999, pressing and sintering at 1150–1170 °C and achieving water absorption values of less than 0.5%. Menezes et al. [156] researched the combination of up to 35% granite sawing wastes in ceramic bricks and tiles formulations in 2005. The findings revealed that ceramic formulations containing granite wastes could be used to render wall and floor tiles with water absorption values less than 3% after firing at 1200°C.

P. Torres et.al., [157]'s study focuses on repurposing wastes extracted from the cutting and polishing of granite and quartzite ornamental rocks as substitute raw materials in stoneware formulations for the manufacture of floor and wall tiles. This research shows that much improved final ceramic body properties could be obtained with basic formulations containing just 30–40 wt.% of a plastic clay with appropriate chemical and mineralogical compositions and 70–60 wt.% of one of the studied sludge or their mixtures and that dumping these residues in landfill is a huge environmental and economic mistake. In addition, the high content of total fluxing oxides found in granite sludge favours the maturation of the ceramic body at lower sintering temperatures, makes it a suitable substitute for feldspar in stoneware tile pieces that meet the most stringent ISO 13006 requirements [157].

Palm kernel shell is a waste product from the agriculture industry that is plentiful in Nigeria. The resulting product, KERNELRAZZO, is the result of research on the use of palm kernels as an aggregate in floor finish by removing either partially or completely the marble chipping in terrazzo [158]. However, after two years of exposure, the surface texture of the kernelrazzo tiles and floor begins to fade. Since consistency is determined by the force of cohesion between particles, the floor finish created by this mixture will not be long-lasting. Granite dust was selected as a fine aggregate to be applied to the mix to serve as a binding agent to increase the strength and resilience of kernelrazzo in order to address these issues. It looked at the positive impact of replacing some of the coarse aggregates with granite dust on kernelrazzo's compressive strength, water absorption ability, and density. As a result, there is a benefit when strength is added and the cost is minimized. Similarly, the existence of granite dust has no detrimental effect on aesthetics. As a result, proposing that to create a strong kernelrazzo floor finish in terms of strength, longevity, density, water absorption capability, and cost will not be out of place [159].

### 2.4.2. Properties of flooring and standard tests methods

When it comes to floor finishing materials, it's important to understand the service and durability requirements. And a procedure for determining these properties using standard methods. In general, abrasion resistance, slip resistance, and wear resistance are critical service requirements, while sorptivity and water absorption capacity is used to determine the flooring materials' durability level.

Wear is characterized as damage to a solid surface caused by relative motion between that surface and a touching substance or substance, which usually involves the progressive loss of material. Abrasive wear, slipping wear, erosive wear, fretting wear, and impact wear are a few examples of wear that are commonly found in realistic contexts, according to various classification schemes [160]. There are many types of wear monitoring techniques. Some tests are designed to determine how a substance reacts to a certain form of wear, such as solid-particle corrosion, slipping wear, or two-body abrasive wear. Other wear tests are designed to simulate a particular field application such that materials, surface additives, and lubricants can be tested for that application [161]. Since wear is a device reaction rather than a material property, a material's wear resistance could vary significantly depending on the wear process and the test conditions. Floor coverings are commonly tested for abrasion resistance [162]. Floor coverings having smooth surface finish could be tested using the method defined in European standard EN 660-2. Also, it can be used to figure out how resistant surfaces are to abrasion wear [163],[164].

The development of a friction requirement for the shoe/floor mix, as well as the use of materials that follow this standard, is needed to control slipping events. Smooth surfaces are commonly thought to be more slippery than rugged surfaces. The coefficient of friction (COF) between the shoe sole and the floor has been found to be heavily determined by the roughness of the floor. Various surface roughness criteria could be used to assess the roughness of a surface [165]. The static coefficient of friction (SCOF) is used to calculate friction between the shoe and the floor, while the dynamic coefficient of friction (DCOF) is used to determine factors affecting slipperiness. Since the foot is in motion as the shoe makes contact with the pavement, the DCOF is expected to be a deciding factor causing slipperiness [166],[167]. In reality, the touch time between the sole and the floor is so brief during regular walking that SCOF can be irrelevant. On the other hand, some literature reported that SCOF was the most important factor influencing floor slip resistance and some were suggested that SCOF is a good display of slipperiness because it governs whether a slip will be initiated [168],[169]. R. Myung et.al., [170] findings showed that, despite the small slipperiness discrepancy, humans have a promising ability to subjectively discern floor slipperiness with a reliable confidence level for the surfaces. They concluded that humans were reliable, albeit dangerous, floor slipperiness discriminators [170]. For some floor tiles, Cohen and Cohen (1994a) contrasted visual judgment with experiment (SCOF). In comparison to Myung et.al., (1993) they discovered a large number of disagreements between subjective answers and the SCOF values of the tiles [171], [172]. Human interpretations of floor slipperiness could vary significantly from the actual traction of the floor as calculated by COF, according to studies by Cohen and Cohen [171] an erroneous sense of floor slickness could lead to an unnatural gait pattern and foot slippage . The term "friction" has long been used to describe how slippery anything is. Furthermore, friction measures have been applied to roughness measurements, and arbitrary measurements have been addressed in addition to friction and roughness measurements [165], [173], [174].

Water absorption potential represents the nature of the body's internal structure and is linked to mechanical strength as well as other resilience-related characteristics including resistance to deep abrasion, stain resistance, and frost/thaw cycles, as well as dimensional quality [175]. The material's serviceability is determined by its durability. Furthermore, material durability is mostly determined by a fluid's ability to infiltrate the material's microstructure, which is known as permeability. Water absorption has long been used to assess the long-term stability in cementitious products [176]. Sorptivity is a moisture transfer index for unsaturated specimens that have recently been recognized as a key indicator of concrete durability and its monitoring determines how much water is absorbed by capillary action. The capillary increase of adsorbed water in a dry sample is reflected by the sorptivity of the substance, which is calculated in terms of the rate of volume of water absorbed by a given surface area of test specimen ($cm^3/cm^2.s^{1/2}$) [177], [178]. The ASTM C1585 standard is widely used to assess the absorption and amount of absorption of water in unsaturated hydraulic cement concretes (also known as sorptivity) [179], [180] .

### 2.4.3. Thermal comfortability of flooring materials

Humans have a remarkable capacity to adapt to a variety of climatic environments. The world in which humans work has a significant impact on the performance of activities done and the psychophysical status of each of them. One approach to ensure a high degree of protection, convenience, and productivity of completed tasks is to provide optimal living conditions by the selection of appropriate building and construction materials. Early identification of environmental causes that have a significant impact on human well-being is critical for taking appropriate steps to correct the microclimate and improve working conditions [181]. Climate change, which is impacting all countries, has a significant impact on building inconveniency [11].

Towards that end, thermal comfort is one of the key points that could affect the occupant's physiological, psychological, and their behaviours and productivity [182]. A good thermal performance could make the indoor temperature fit occupants' comfort level [11]. Besides ecological and economic issues, construction technology highly values utilitarian aspects. The goal of architecture is to create a building envelope that is visually appealing, durable, and watertight, while also offering a high degree of thermal comfort inside. This comfort is characterized as a state of equilibrium between the amount of heat created by living organisms during metabolic reactions and the amount of heat lost through heat radiation, convection, and conduction. The heat exchange between the human body and the atmosphere is the result of a complex interaction of forces that function together to maintain the organism's thermal equilibrium. The level of comfort is influenced by both environmental and human influences [181].

Buildings, all over the world, consume large energy amounts as the majority of these amounts go towards either cooling or heating the buildings. The surface temperature, (e.g., flooring, ceiling or walls) are the main elements that affect the temperature of the building and thermal comfort consequently the amount of consumed energy. Air temperature, surface materials, radiant temperature, air circulation, humidity, human behaviour, clothing, and other aspects all contribute to a building's thermal comfort [183], [184]. The potential of a material to withstand or mitigate the influence of heat flow is known as thermal resistance. It is determined by temperature and thermal conductivity. To change the temperature of high density materials like concrete, bricks, and tiles, for example, a considerable amount of heat energy is needed. Several studies have investigated the role of thermal mass in determining human thermal comfort in particular buildings [182]. Authors in [185] showed how thermal mass combined with optimal building operation can regulate the building's internal temperature to maintain comfortable internal conditions of buildings. Sunlight enters the room in the mornings, and the heat is drained by the flooring, keeping the room at a cool temperature. In the evenings, the floor releases the observed energy (during the day) and adds warmth to the room and that is the cooling phase. The question is what happens if an appropriate flooring material is used or flooring material with insufficient thermal mass is used? In that case, the heat coming from the sunlight would be reflected into the room, because the floor would not be able to store/absorb it, and that would cause low human thermal comfort as the room will be very warm. In addition, during the nights, and as the flooring material did not store any energy, the room temperature would be very low and that again would cause low thermal comfort for the occupants [182].

The effect of flooring on human thermal comfort could be attributed directly to a series of experiments performed by Kansas State University researchers in 1964 [186]. The human thermal comfort point was established for various flooring temperatures and activity levels by the researchers. The study of flooring materials is more difficult and time-consuming since each material will hold/store heat at various amounts and the volume of accumulated energy/heat does not remain constant over time [182]. Thermal comfort is critical, not only to control the indoor environment to satisfy the occupants but also for other different reasons such as achieving better air quality, controlling energy consumption, greener environment by reducing the emission of $CO_2$, enabling efficient work environment [187].

### 2.5. Floor coatings and Resins

Without hesitation, the floor is the most used feature of a building that is exposed to static and dynamic stress, chemical reactions, and repeated washings. Therefore, the top surface of floor finishing materials must have several characteristics such as high resistance to water or chemical absorption, skid resistance, wear resistance, etc. Epoxies account for the majority of the different varieties of resins found in floor coatings. Epoxy coatings are best known for their chemical and mechanical resistance, as well as their ease of washing and water tightness, even in thin layers [188]. The necessity of providing supplementary protection is important since the floors are subjected to continuous cleaning, washing and wearing due to walking.

There are several strategies for protection in various ways. Two of them are the use of protective surface coatings and epoxy and polymeric coatings. As a flooring material, it is required to prevent both ware and water absorption.  Surface coatings are usually made of drying or semi-drying vegetable oil. Without the use of some solvent, vegetable oil may be used to make free-flowing coating products. This makes it easier to form a solvent-free coating, without the need for volatile organic content [189]. Coating protective efficiency was determined by measuring water-stone contact angle, water absorption by capillarity and water vapour permeability [190]. The durability was determined by water absorption, chloride permeability, and chloride diffusion and chemical resistance [191]. A. Tsakalof et.al.,[190] recommended that for wet service conditions the epoxy chlorinated rubber and acrylic-based coatings are better. Different synthetic coatings have been used for stone protection such as acrylic and siloxane polymers, perfluoroethers, fluorinated polyolefins. The selection of coating should be economically efficient to avoid any physical or aesthetic deterioration of the product and according to this findings, the suitability of coatings is different for different surface materials [190], [192].

The concrete surface could be protected in a number of different ways. Epoxy resin and polymer coatings are two of them. However, substantial progress in understanding the processes of commercially active surface treatment chemicals has been achieved for a long period. A novel family of surface treatment chemicals has also emerged in the last 20 years [192]. Surface treatment agents are categorized into two groups depending on their chemical composition as inorganic and organic treatments. Sodium silicate solution ("water glass") is the most effective and common inorganic surface treatment. They do have a short service period and are impossible to uninstall after their safety properties have worn off [194], [195]. The most used inorganic surface treatment is sodium silicate solution (water glass). Potassium silicates, lithium silicate, and fluosilicates have also been reported to be used for inorganic surface treatments rarely [196]. Despite the fact that inorganic coatings are more durable, they have received less attention, particularly in terms of penetration depth and interactions with the cementitious foundation.

The surface treatments are classified into three groups based on their roles as hydrophobic impregnation, impregnation, coatings and combination of these three types are called multifunctional surface treatment in EN 1504-2:2004 [197]. The surface coating forms a continuous polymer film which acts as a physical barrier to enter the water inside the substrate[198], [199], [200]. Common polymer coatings, polymer/clay nano-composite coatings, and cementitious coatings are only a few examples of surface coatings. Common barrier coatings such as epoxy resins, acrylic, and polyurethane have been used in the building industry for many years [201]. Polyurethane coatings do well in terms of covering concrete and do not shrink. The barrier effect of the polymer coating is primarily responsible for the coated concrete's water resistance. Coatings are typically made up of multiple layers in modern architecture to create a stronger protective effect. Furthermore, researchers have made several attempts to enhance their properties by using different nano-fillers. Because of their superior properties to virgin polymers, polymer nano-composite coatings have recently sparked a lot of interest in academic research and engineering applications. The tensile modulus, abrasion resistance, and heat resistance of polymer nano-composite coatings and thermal resilience than traditional coatings are all high [198] [199].

The most popular cementitious coatings used for concrete surfaces are polymer-based cementitious coatings. Polymer-adapted cementitious coatings are a combination of cement, aggregates, and a polymer. The addition of polymer to cement paste significantly enhances its strength, stability, adhesion, chemical resistance, and inpermeability [202].

Geo-polymer coatings are more common than organic polymers in highly hostile conditions because they are more durable. Geo-polymer also has a glassy feel, making it resistant to vandalism [199]. Due to their superior mechanical, chemical, and thermal resistance properties, geo-polymer has potential in fire resistant and defensive coatings for various surfaces, including metal and concrete. However, geo-polymer shrinkage should be treated with caution, as it could lead to coating failure [198].

Surface treatments offer varying types of protection based on the state of the concrete substrate and the application procedure [195]. To ensure good concrete surface treatment, a detailed understanding of the factors that influence surface treatment efficiency, such as air permeability, bonding strength, penetration depth/coating thickness, and so on is needed. Furthermore, breathability has an effect on the adhesion of coatings to the concrete matrix Surface treatments should adhere well to the concrete substrate, ensuring long-term performance and concrete protection. According to previous studies A. Tsakalof et.al., [190], the coating bonding power could be between 1.4 and 1.75 MPa. The average bond strength of different epoxy coatings is between 2.9 and 4.0 MPa, according to J.-G. Dai et.al., [197], while that of cementitious mortar is between 2.2 and 3.3 MPa. The properties of the coating and primer, the condition and state of the substrate, and the process of applying coatings all have an effect on these adhesions [202], [203]. Researchers discovered that the surface roughness of a substrate can affect coating adhesion, and that the roughness is dependent on the substrate's compressive strength and aggregate properties. One of the most important factors affecting the reliability and durability of overlays is their adhesion to the concrete substrate [204], [205]. The high adhesion causes higher tolerance on non-compatibility of properties of both materials [205]. However, it was found that organic coatings will degrade after aging [199].

A pull-off test is recommended for the assessment of bond strength and bond quality in many standards and guidelines, e.g. new European Standard EN 1504-10 [206]. In the case of large-area objects like factory floors, adhesion regulation is important [204], [207].

For calculating the bonding strength of coatings, ASTM D 4541 and ASTM C321-00 could be modified. A diamond driller is used to remove the middle portion of the coating from the whole coating scheme in ASTM D4541, and a metal plate is applied to the coating using a fast setting epoxy. The tension applied to the metal sheet as the coating breaks from the surface is proportional to the bonding strength. This approach is generally used for in-situ testing, but it takes a long time [208], [209].

### 2.5.1. Phenol-formaldehyde resins

Phenol-formaldehyde resins, the first synthetic commercial polymer resins, were discovered over a century ago. The resins have been used commercially in a number of uses, including moulding additives, laminates, adhesives, and shell moulds for metals and electrical insulation, due to their low cost, dimensional flexibility, and high tensile strength. A great deal of research has gone into studying the curing chemistry of these resins over the last 50 years [210], [211], [212]. Phenol–formaldehyde resins are among the oldest synthetic polymers, having been developed first [213], [214]. It was first commercialized in 1909, and they have since been used in a variety of markets, including refractories, composite materials, adhesives, thermal insulation, and the electrical industry. Phenolic resins are the condensation products of phenol and aldehydes, especially formaldehyde, which are then converted into high molecular mass polymers during curing reactions. The reaction of phenol and formaldehyde produces two types of phenol-formaldehyde resins: novolac and resole resins, which are produced under acidic or alkaline conditions, respectively [214].

The novolac was made by combining phenol and paraformaldehyde with oxalic acid in a stainless steel reactor [215], [216]. Most methods are impractical to use or fail to offer substantial structural details because the curing reactions are very complex and the cured resins are invariably strongly cross-linked compounds that do not melt or dissolve. A thorough understanding of the curing chemistry, which is responsible for many desirable properties and is essential for expanding the use and alteration of resins, has yet to be attained. Since the curing reactions between novolac resins and HMTA started at 90-120°C, the sample remained soluble in a solvent such as acetone. The temperature at which the curing starts tends to be lower while the original HMTA content is lower. decreasing the amount of HMTA was found to change the curing process [217]. Several methods have been suggested for the early stages of HMTA cure of novolac. According to early literature, the initial curing is a homogeneous acid-catalyzed reaction requiring a trace amount of water in the novolac to hydrolyze HMTA to a-amino alcohols, and the reaction rate rises as the pH of the novolac resins decreases and the phenol or water content increases [218], [212].

Other claims suggested excess water could decrease the reaction rate. An intermolecular hydrogen-bonding mechanism between novolac and HMTA was proposed by [219]. The nitrogens in HMTA will hydrogen bond to the phenolic protons in novolac chains that were previously self-associated through hydrogen bonding. In the novolac reaction with HMTA, two successive and temperature-dependent steps occur as the temperature rises.

Before curing, the phenolic hydroxy group of novolac and the nitrogen of HMTA form a hydrogen bond. When the curing temperature is increased to 90-120°C, the curing reactions begin. Curing reactions are unquestionably complicated, and a number of mechanisms may be involved. The amount of HMTA present at the start of the curing process is crucial to the curing rate and chemical composition of fully cured resins. A comparatively significant volume of HMTA and resins with more ortho-reactive sites can be used to achieve a cross-linked novolac network of more stable nitrogen-containing structures [220], [221]. Free HMTA could be removed during the washing process by the water [222]. The reaction between novolac and HMTA in solution is realized at the temperature of 80 0C which is much lower [216].

Novolac resins are oligomer chains that are linearly branched and have a low molecular weight. Several organic solvents are soluble in these thermoplastic resins. The oligomers become connected into a three-dimensional strongly cross-linked network during the curing reaction with hexamethylenetetramine (hexamine) [213].

The method of hexamine curing of novolacs has been researched by several scholars, however, the various potential intermediates complicate the study. M. I. Aranguren et.al., [215] have identified 15 possible intermediates in hexamine-cured novolac. The suggested mechanism involves the production of initial intermediates such as benzoxazines and benzyl amines, as well as their decomposition, oxidation, and/or further reactions into methylene bridges with residual traces of amines, imides, imines, methyl phenol, and other compounds [214].

### 2.6. Summary

Many engineering building materials use a considerable amount of energy and releases a high amount of greenhouse gases during their production and transportation. Using local materials and in-situ cast constructions could help minimize energy demand and environmental effects. The need for sustainability and how it is achieved by proper construction design and planning have been identified in literature. It was discovered that building materials play an important role in the development and construction of a prosperous future. As a result, extensive efforts have been made over the last few decades to consider what materials can be used for sustainable features.

A few indicators were defined to measure the sustainability for construction materials through cost effectiveness, social acceptability and harmful effect on health and environment during the production and construction process today and future. Wool bricks, paper insulations, are the few sustainable construction materials and earth based technology are widely used sustainable material among several such materials. Therefore, the use of soil/earth as a construction material and earth /soil based materials already available was found out during the literature survey. Rammed earth, compressed earth bricks, mud concrete blocks could be found as the available building construction materials based on soil using for wall construction. It was discovered that there is a knowledge deficit about the prospect of using earth/soil as flooring materials. Therefore, soil used as a construction material was reviewed deeply. The literature has recognized the importance of using soil as a construction material in tropical climates to improve thermal compatibility within the building and thereby save energy. Since determining that there is a need for sustainable alternative flooring materials and that the earth still has a knowledge gap to use as flooring, a literature review was conducted to determine the existing flooring materials and their production process, raw material used and raw material extraction process, and the effect of all of these processes on the environment, eco, and biodiversity. The current floor materials' properties were also established. Eventually, the literature was used to determine the appropriate durability and service characteristics, as well as the standard test methods of flooring materials as the primary goal of this study is to incorporate a soil-based flooring material. Abrasion resistance, slip resistance, wear resistance, thermal comfortability was identified as the main required service characteristics while soptivity and water absorption, shrinkage was identified as the main requirement for the durable and aesthetic floor. Finally, a study of available surface protection materials was undertaken in order to use the right surface finish for the flooring material that will be developed. The surface treatment techniques, surface treatment materials, how they act as surface protection, and how they react with the substrate were all thoroughly examined using the literature available. With all the knowledge gathered through literature review, the research commenced to develop a soil based flooring material.

# CHAPTER 3 : MIX DESIGN FOR SOIL FLOORING

## 3.1. General

The term "floor" refers to a housing unit that consists of an aggregate or mortar (commonly referred to as a fill or a base) covered by a plaster (commonly referred to as the floor) with a wash coat applied to the top [70]. Firstly, to find out the flooring material, the floor base has to be developed in this background. Therefore, in this chapter, a thorough investigation of the soil-based flooring material development techniques would be carried out. A strong soil concrete as a floor base was created first, followed by the top coating. The construction of the floor base concrete was commenced by the using soil as the main raw material. Soil is made up of fine particles, sand, and gravel mixed in various proportions. As a result, the ideal particle size distribution and gravel size to achieving a concrete mix with the requisite strength for floor concrete are essential. Therefore, the suitable particle size distribution was discovered through series of experiments. Cement was used as a stabilizer to strengthen the soil. The requisite amount of cement, the optimal water-cement ratio, and the best test sample size were also identified in this context. The material selection and process of mix design for floor base will be discussed in this chapter. The layout plan shown in Figure 3-1 depicts the process of completing the task.

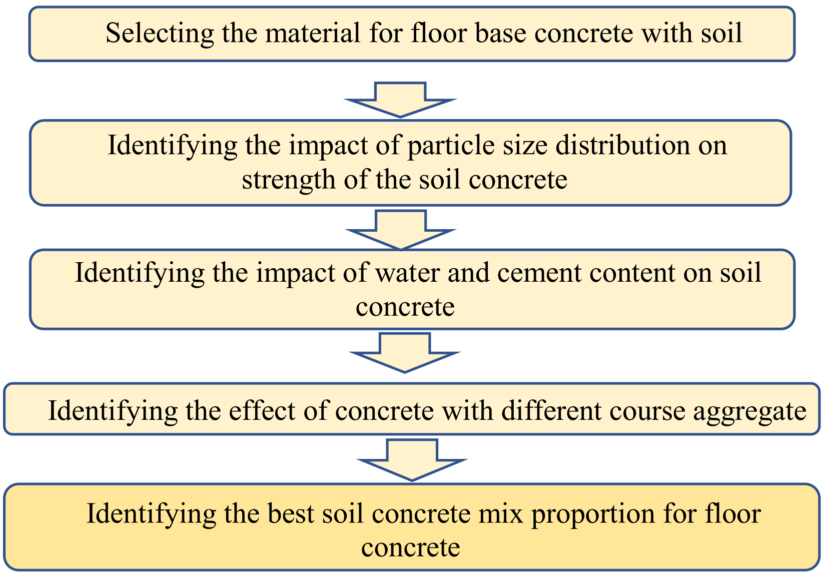



*Figure 3-1: Methodology layout of mix design of floor concrete*

### 3.2. Materials used for the floor base

Soil, cement, and water were used as the main ingredients to produce soil concrete. Soil is used as the main matrix while cement is used as a stabilizer and water as a binding agent. The main materials used are shown in Figure 3.2.


*(a) Extracted Soil* *(b) Ordinary portland Cement* *(c ) Water*

*Figure 3-2: Main materials used to produce the soil concrete*

#### 3.2.1. Soil

Soil is the main matrix used in this study and it was excavated from the University of Moratuwa premises for this research. This extracted soil was stored in a covered place to prevent external disturbance.

#### 3.2.2. Water and Cement

The required water for this experiment series was taken from the national water supply and drainage board. Ordinary Portland cement was purchased in the same cement brand throughout the experiment to avoid the effect of cement property changes since the previous studies revealed that the cement percentage was affected by the strength and durability characteristics of the soil-cement products [9], [5].

### 3.3. Mix development

construction of the floor base concrete was commenced by the use of soil which was made up of fine particles, sand, and gravel was mixed in various proportions. Suitable mix proportions development for soil concrete to achieve required strength was done step by step. The main variable identified were the optimal water-cement ratio particle size distribution and gravel size and cement requirement. Therefore, optimum values of these variables were found out in this section.

### 3.3.1. Initial water requirement for a workable mix

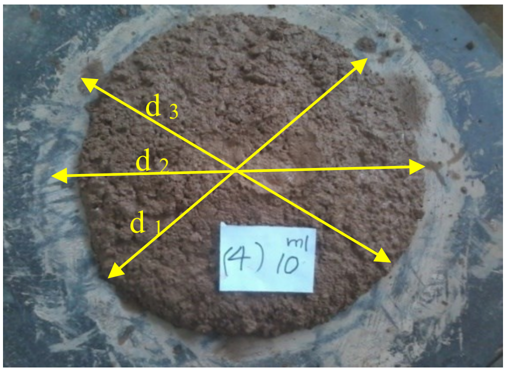
The main objective of the soil based concrete mixture was to develop a self-compacting mix that would be able to compact and set as strong concrete under its own weight without any mechanical vibration or compaction effort. Therefore, it was critical to control the fluidity of the soil mixture while maintaining its consistency and resilience in order to design it as a self-compacting mix. As a result, the water became an important component of the mix. The initial task was to determine the proportion of water required to achieve the self-compacting concrete. Generally, flow table tests and slump tests are used to measure the workability of cement concrete. Since there is no standard method written to follow the self-compacted mix developed through soil based material in the literature, these two methods were used initially. Extracted soil from the ground was mixed in constant cement % (18%) from dry soil by varying the added water amount from 2000 ml up to 4000 ml @ 500 ml intervals. For each water content value, three workability tests were performed. The standard slump tests apparatus and flow table used for this investigation are shown in Figure 3.3 below. The flow table test was performed according to the BS 1881 part 105 of 1984 and the slump test was performed in accordance with ASTM C 143/C143M-20 [223], [224].

*(a) Flow table* *(b) Slump test apparatus*

*Figure 3-3: Slump and flow table apparatus*

The Slump cone was placed on top of the flow table and was filled in three layers with a prepared soil concrete mix in one process. The excess mix from the test cone's top was removed while allowing 60 seconds for the cone to stand. The cone was then raised in a single motion. However, because of the cohesiveness of the material, the soil concrete mix did not disperse immediately.

However, a small height of slump could be seen in this context which did not representing the actual workability. Therefore, 15 blows were applied within 15 secs, and then the flow diameter was measured in three different directions as shown in Figure 3-.4. The average flow Diameter [d average = $(d_1+d_2+d_3)/3$] was calculated. With the maximum spread of about 500-600mm diameter of a circle while giving 15 constant blows, the proper workability of the mix could be achieved. Consequently, three samples from each mix were oven-dried to calculate the moisture percentages of mixtures.


Average flow diameter (d) = $(d_1+d_2+d_3)/3$

*Figure 3-4: Workability tests (slump test and flow table test)*

The average slump height and average flow diameter values for different water content values of soil mix are shown in Table 3.1. According to the results it was observed that the increase in water content the flow diameter and slump height had increased in this background. The flow diameter 500 mm - 600 mm, the proper workable soil mix could be achieved and a further increase in water was a case to segregation. Therefore, it was concluded that the best moisture percentage from dry soil for soil cement mix was 16% - 19%. Because, it was identified that the lesser water percentage (less than 16%) was not provide sufficient workability to have self-compacting concrete and more water (higher than 19%) cause to segregated the aggregate. The variation of the workability of soil cement mix is shown in Figure 3.5.

*Table 3-1: Slump height and flow diameter with different water content*

| Added water quantity (ml) | Moisture (%) | Slump height (mm) | Flow diameter (mm) |
|---|---|---|---|
| 2000 | 15.5 | 85 | 450 |
| 2500 | 16.7 | 100 | 530 |
| 3000 | 17.0 | 135 | 550 |
| 3500 | 18.5 | 180 | 620 |
| 4000 | 19.7 | 250 | 700 |

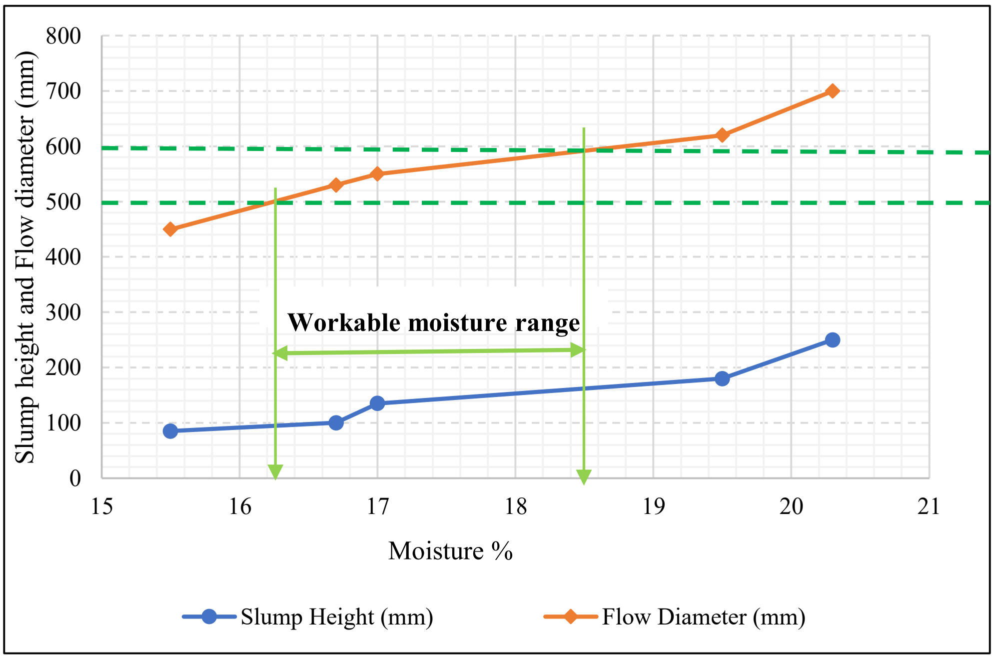



*Figure 3-5: Variation of workability of soil cement mix with moisture %*

The compressive strength of a cube is the basic and universally accepted unit of measurement for specifying the quality of concrete as it is an indirect measure of the durability of the product. Therefore, the next step was to determine the best mix of soil concrete to achieve the standard compressive strength required for the floor base. It was done by changing the variables as stated in the research process above. The added water quantity, cement percentage and particle size distribution are the main variables that could be affected toward the strength of the mix. Therefore, the optimum requirement of these values is identified. As an initiation, the best particle size distribution was analyzed by keeping the other two variables (water, cement) constant.

### 3.3.2. Determining the best particle size distribution

Extracted soil from the ground is the combination of fine particles, sand and gravel in different percentages. The properties of soil constructions strictly depend on its constituent (i.e. gravel, sand, silt, and clay proportions of the soil). Cracks would appear if there is too much clay, and crumbling could occur if there is too much sand [225]. Thus, it is important to consider the constituents of extracted soil and determine the suitable particle size distribution in developing soil flooring material.

According to Adam M Neville and J J Brooks [125], grade 15 concrete (i.e. 15 $N/mm^2$ compressive strength) is used for floor concrete that is laid as a mass concrete (floor concrete) without reinforcing. Therefore, the focus in this mix design was to find out suitable mix proportions to achieve 15$N/mm^2$ compressive strength.

Firstly, two laboratory analyses were performed to determine the constituents of the extracted soil. These experiments should provide a primary description of the properties and constituents of the soil that would be used in the floor concrete preparation. The sedimentation test and the dry sieve analysis were the two measures.

#### 3.3.2.1. The Sedimentation Test

For the sedimentation test, a transparent cylindrical container with a 0.5-liter capacity was filled with soil and water in a 1/4: 3/4 height ratio. The soil and water were carefully mixed before being sealed with a glass lid. The sedimentation layers were analyzed for relative proportions after the cylinder containing the soil and water was set aside for 24 hours. The percentages of each fraction were then determined by calculating the depth of each layer.

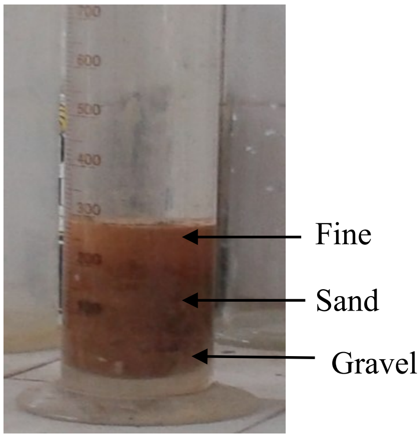
Gravel was deposited at the bottom of the sedimentation test, followed by sand, silt, and clay at the end. The proportion of each particle size could be shown by the depth of each layer. These percentages are just estimates. Since the layer of gravel, which has more voids, seemed to be deeper than the layer of clay, which has few voids. After 24 hours, it was discovered that the chosen soil contained roughly 10% fine particles, 60% sand, and 30% gravel.

#### 3.3.2.2. Particle size distribution - Sieve Analysis

Randomly three soil samples were selected from the extracted soil and were kept inside the oven to dry. All the sieves had been thoroughly washed and were set in descending order. The soil sample (5 kg) was then put on the top sieve, and the test sieves were agitated, causing the sample to move in an erratic motion over the sieves. Particles were held by hand to see if they would fall through without being moved. Consequently, the quantity of soil retained on the test sieves were weighed. The average amount of soil retained in all sieves should be less than 0.1 percent of the total mass of soil. According to the average sieve analysis test results and sedimentation test results, the extracted soil contained 7 % fine particles, 63% sand particles, and 30% gravel particles.

The arrangement of the sieve analysis test and sedimentation test were shown in Figure 3-6 and the results of the sieve analysis test were shown in Figure 3-7. With these results, experiments were commenced to find out suitable optimum particle size distribution for the flooring material.

(a) Sieve Analysis test




(b) Sedimentation test

*Figure 3-6: Arrangement of sieve analysis test and sedimentation test*

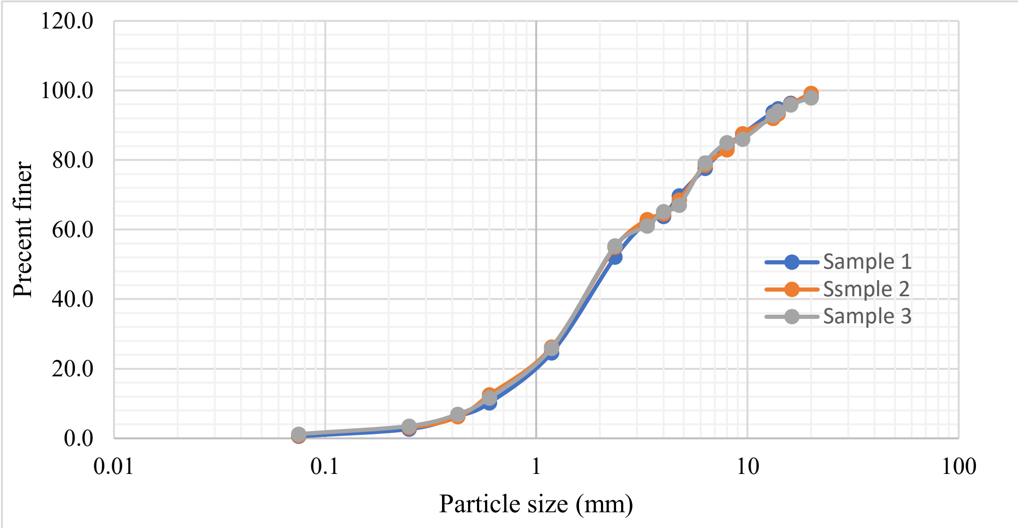



*Figure 3-7: Particle size distribution results*

3.3.2.3. The effect of the fine particle content on the strength of soil concrete.

This step describes the process which was done to determine the optimum fine particle content for the required strength. Initially, the particle size distribution of extracted soil was rearranged by varying fine percentages. Gravel and sand particles were added to the calculated quantity as fine particles from the soil are difficult to change. Table 3-2 shows the mix design used while sample steps involved in the estimation is shown in Table 3-3. The soil was mixed by keeping the cement content and added water content constant to make a soil concrete. 18% of cement and 19% moisture content was used in this context.

*Table 3-2: The mix design to analyze the optimum fine particle content (%)*

| Sample No | Fine % | Sand % | Gravel % | Cement % | Water % |
|---|---|---|---|---|---|
| S1 | 5 | 60 | 35 | 18 | 19 |
| S2 | 10 | 55 | 35 | 18 | 19 |
| S3 | 15 | 50 | 35 | 18 | 19 |
| S4 | 20 | 45 | 35 | 18 | 19 |
| S5 | 25 | 40 | 35 | 18 | 19 |
| S6 | 30 | 35 | 35 | 18 | 19 |

*Table 3-3: Calculation to develop the existing soil to required compositions for soil concrete*

| Sample weight (kg) | Existing proportions (%) | | | Proposed proportions (%) | | | Proposed weight (kg) | Weight to be added (kg) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Clay | Sand | Gravel | Clay | Sand | Gravel | | Clay | Sand | Gravel |
| 14.0 | 7.0 | 63.0 | 35.0 | 5.0 | 60.0 | 35.0 | 19.6 | 0.0 | 2.9 | 2.7 |

Once the particle size distribution was corrected, to validate the particle size distribution of new soil sample, a sieve analysis was performed again. The prepared soil sample is shown in Figure 3.8.


*Figure 3-8: Preparation of soil to the required particle size distribution and developed soil*

Once the soil was ready, three cubes consisting of the dimensions 150mm x150mm x 150 mm from each mix were cast to determine the compressive strength. The cubical samples were cast in steel mould as shown in Figure 3.9. Figure 3.10 shows the soil concrete mixing and casting process.

*Figure 3-9: Steel mould used for specimen casting*

*(a) materials mix in dry condition* *(b) adding water*

*(c ) Soil concrete* *(d) Cube casting process*

*Figure 3-10: Soil concrete mixing and Specimen preparation*

The cubes were demoulded after 24 hr from the casting and all the cubes were cured under equal conditions until the time of testing.  After 28 days from the casting, all the cubes were tested for dry compressive strength.

The universal compressive strength testing machine was used to test all the specimens for compressive forces, and the tests were carried out in compliance with BSEN 12390-3:2009 [228]. The size of the specimens was measured to the nearest mm before samples were kept in the testing machine. Each soil block was carefully positioned in the testing machine underneath the upper bearing plate's centre. A universal compressive strength measuring machine with a capacity of 2000 kN was used to apply an axial compressive load at a constant rate of 6.8 kN/s, and the load was steadily raised until the specimen failed. The compressive strength was determined using Equation 3-1 with the aid of the failure load. Figure 3.11 shows the testing procedure.  The Figure 3-12 shows the compressive strength variation with the fine particle content.

$$\boxed{\text{Compressive Strength} = \frac{\text{Failure Load}}{\text{Load applied Area}}}$$

*Equation 3-1*

*Figure 3-11: Compressive strength testing procedure*

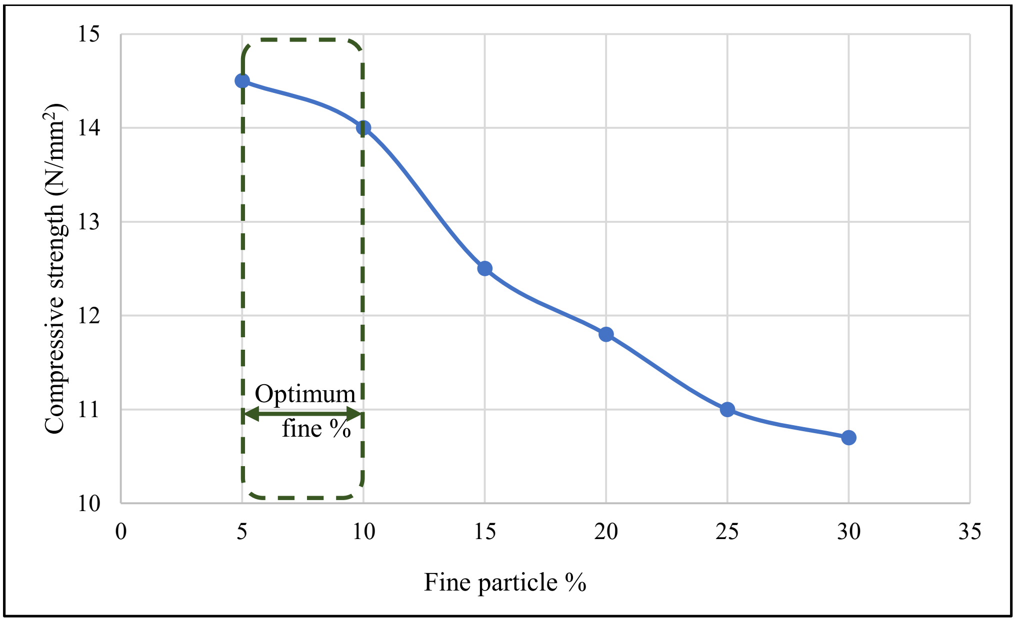



*Figure 3-12: The variation of compressive strength with fine particle content*

According to the findings, an increase in fine particle content causes a decrease in compressive strength, and the optimum fine particle content is between 5% and 10%. The impact of gravel size and percentage presence on strength was then considered.

3.3.2.4. The effect of gravel content on the strength of the soil concrete

After concluded the optimum fine particles content, the effect of the gravel percentage in the soil on the strength of soil concrete was analysed. The soil concrete mix was done by varying gravel percentages. The fine particle content decided with the above results was kept constant as 5%. Soil concrete was made by keeping the cement (18%) and water (19%) constant. In this step, steel cubes which has the same dimensions were cast. The mixing, casting, testing procedure was the same as described in section 3.3.2.3. The mix proportions arranged for this evaluation are shown in Table 3-4. The extracted soil was rearranged by doing calculations as in Table 3-3.

The results obtained in this step are shown in Figure 3-13. According to the results obtained it could be concluded that the optimum gravel percentage is between 30% to 35%.

*Table 3-4: Mix proportion plan to evaluate the gravel % on soil concrete strength*

| Sample No | Fine % | Sand % | Gravel% | Cement % | Water % |
|---|---|---|---|---|---|
| A1 | 5 | 85 | 10 | 18 | 19 |
| A2 | 5 | 75 | 20 | 18 | 19 |
| A3 | 5 | 65 | 30 | 18 | 19 |
| A4 | 5 | 55 | 40 | 18 | 19 |
| A5 | 5 | 45 | 50 | 18 | 19 |
| A6 | 5 | 35 | 60 | 18 | 19 |

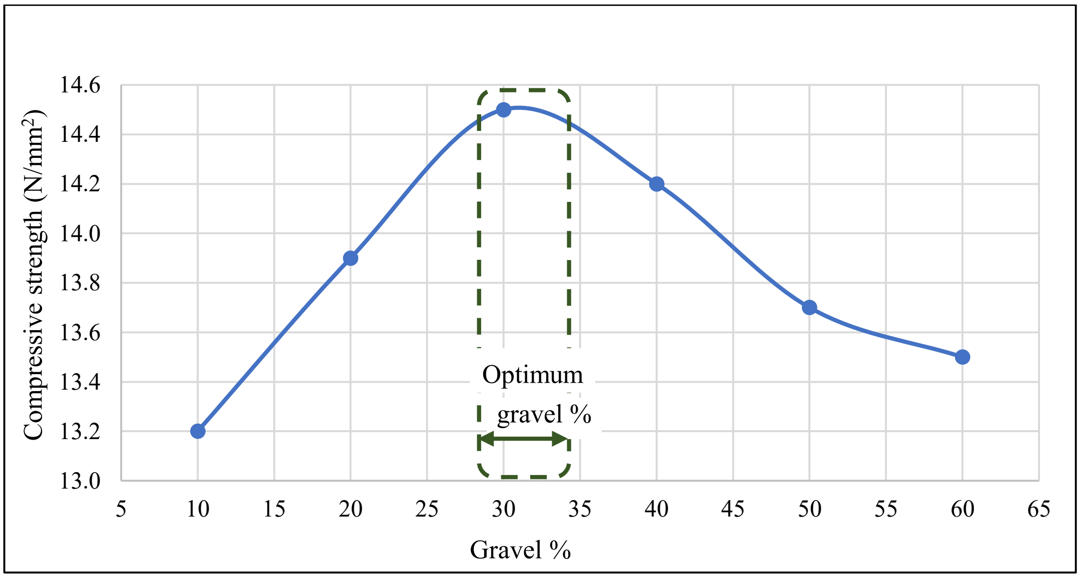



*Figure 3-13: The variation of compressive strength with gravel %*

According to the overall results obtained in the above two sections, it could be concluded that the optimum fine particle content was between 5%-10% and the optimum gravel percentage was between 30%-35% to produce the best soil concrete. Next, the experiment was done to investigate the variation of compressive strength of soil concrete with the gravel size.

#### 3.3.2.5. The effect of the gravel size on soil concrete

Similar to concrete technology, shape and the size of aggregate also impacts the workability, durability, strength, weight and shrinkage of concrete [125]. Therefore, the investigation of the effect of gravel size on the soil concrete has become essential. Therefore, this step is to investigate the effect of the gravel size on the soil concrete.

According to the 'Unified Soil Classification System' - ASTM D 2487 [227] any soil could be classified as, 4.75 mm < Gravel < 75 mm, 0.425 mm < Sand < 4.75 mm , and 0.075 mm < Fine < 0.425 mm. Since the gravel size governs concrete strength, it is vital to find the correct size of gravel that is used to make soil concrete for proper strength. With the previous results in the above sections it could be concluded that the particle size distribution affects the compressive strength of the soil concrete. In this section, the gravel, the sand and fine particle percentages were kept constant at 35:60:5 which is the optimum suitable percentage for soil concrete. Cement and water percentages were also kept constant at 18% and 19% respectively. The mix was designed by varying the gravel size as shown in Table 3-5.

*Table 3-5: Mix design to find the optimum gravel size*

| Mix code | Gravel size range |
|---|---|
| P1 | 4.75-10 |
| P2 | 4.75-20 |
| P3 | 4.75-30 |
| P4 | 4.75-40 |
| P5 | 4.75-50 |

150mm x150mmx150mm cubes were cast from all mix codes considering three from each. Then the cubes were tested for compressive strength and results could be shown in Table 3-6. Figure 3.14 shows the variation of compressive strength with gravel size.

*Table 3-6: Compressive strength for the different gravel size range*

| Mix code | Gravel size range (mm) | Compressive strength (N/mm2) |
|---|---|---|
| P1 | 4.75-10 | 13.25 |
| P2 | 4.75-20 | 13.40 |
| P3 | 4.75-30 | 13.35 |
| P4 | 4.75-40 | 13.25 |
| P5 | 4.75-50 | 13.20 |

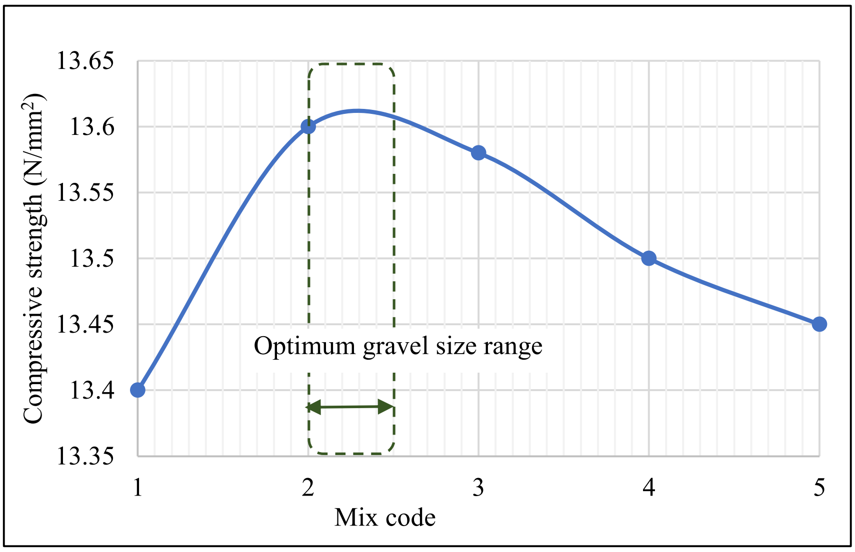



*Figure 3-14: Compressive strength variation for the different gravel size range*

The findings revealed that as the gravel size increased, the compressive strength increased at first, but as the size increased further, the strength decreased. The results show that the maximum strength was given for the mix code 1 and 2 (P1 &P2). This is the gravel size which is between 4.75 mm - 20.00 mm and 4.75mm - 30 mm. This concludes that gravel sizes 4.75 mm - 25 mm would be the optimal gravel size for floor base compressive strength. Thus, these findings were used to guide future investigations.

The optimum constituent of soil for strength requirement was now concluded and for further development, the possibility to use the rubble in the range of optimum gravel size was investigated.

### 3.3.3. The behavior of soil concrete with different course aggregates

This floor base was made out of the soil, and the gravel particles in the soil were considered as coarse aggregates. The behaviour of soil concrete properties with a different type of course aggregate other than the gravel particles was analyzed too. According to the soil investigation results, native soil contains fine particles in the range of 10% to 15% [7], [161]. Soil concrete results obtained above conclude the best fine particle content is between 5% - 10%, and the gravel content is between 30% - 35%. According to the previous research for the mud concrete block the best fine particle content is < 10%, sand content 55 % - 60%, and gravel content 30% - 35%. But the existing soil extracted from the ground has always been incompatible with the required soil particle proportions (%) for this soil concrete. Therefore, to obtain the required gravel, sand, and fine particles to the required proportions, it is essential to remove fine, or sand particles in some percentage. However, it is not practicable to remove fine particles in a practical situation. Therefore, to make the soil in the required composition, gravel particles were added. Instead of adding gravel particles, this step evaluates the possibility to replace the gravel partially or fully with the crushed rubble which has particle sizes in the gravel range. The test specimens were cast in two cases by varying the gravel percentage and adding metal in the size range of the optimum gravel range concluded in the above section (i.e 4.75 mm < gravel < 25 mm). For both cases, the water quantity, cement content, as well as fine percentage and sand percentage in the soil were kept constant. Figure 3-15 shows the main raw materials (soil, metal particle) used in this context.

*(a) Extracted Soil* *(b) rubble particles*

*Figure 3-15: Main materials used for test sample preparation*

The first case was designed to analyze the strength by replacing the total gravel amount with rubble. The second case was designed to analyze the strength of soil concrete by partially replacing the gravel content with the rubble. In both cases, 150 mm x150 mm x150 mm cubes were cast according to the mixed design as shown in Table 3-7. The calculation procedure is shown in Table 3-8. Five mixtures were prepared for each case and for each mix three cubes were cast to determine the compressive strength. Altogether 30 (3 cubes x 5 mixes x 2 cases = 30) cubes were cast using the same steel moulds.

*Table 3-7: Sample preparation plan*

| **Case one** | | | | **Case two** | | | | |
|---|---|---|---|---|---|---|---|---|
| **sample no** | **sand %** | **clay %** | **metal %** | **sample no** | **Sand %** | **clay %** | **gravel %** | **metal %** |
| C1S1 | 75 | 5 | 20 | C2S1 | 75 | 5 | 35 | 0 |
| C1S2 | 65 | 5 | 30 | C2S2 | 65 | 5 | 24.5 | 10.5 |
| C1S3 | 55 | 5 | 40 | C2S3 | 55 | 5 | 17.5 | 17.5 |
| C1S4 | 45 | 5 | 50 | C2S4 | 45 | 5 | 10.5 | 24.5 |
| C1S5 | 35 | 5 | 60 | C2S5 | 35 | 5 | 0 | 35 |

*Table 3-8: Calculation procedure to develop the soil with rubble*

| Sample weight (kg) | Existing propotions (%) | | | | Proposed propotions (%) | | | | Proposed weight (kg) | Existing weight (kg) | | | | Final weight (kg) | | | | Weight to be added (kg) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Clay | Sand | Grvel | metal | Clay | Sand | Grvel | metal | | Clay | Sand | Grvel | metal | Clay | Sand | Grvel | metal | Clay | Sand | Grvel | metal |
| **Case 1** | | | | | | | | | | | | | | | | | | | | | |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **75.0** | **0.0** | **20.0** | 19.6 | 1.0 | 8.8 | 4.2 | | 1.0 | 14.7 | 0.0 | 3.9 | 0.0 | 5.9 | -4.2 | 3.9 |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **65.0** | **0.0** | **30.0** | 19.6 | 1.0 | 8.8 | 4.2 | 0.0 | 1.0 | 12.7 | 0.0 | 5.9 | 0.0 | 3.9 | -4.2 | 5.9 |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **55.0** | **0.0** | **40.0** | 19.6 | 1.0 | 8.8 | 4.2 | 0.0 | 1.0 | 10.8 | 0.0 | 7.8 | 0.0 | 2.0 | -4.2 | 7.8 |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **45.0** | **0.0** | **50.0** | 19.6 | 1.0 | 8.8 | 4.2 | 0.0 | 1.0 | 8.8 | 0.0 | 9.8 | 0.0 | 0.0 | -4.2 | 9.8 |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **35.0** | **0.0** | **60.0** | 19.6 | 1.0 | 8.8 | 4.2 | 0.0 | 1.0 | 6.9 | 0.0 | 11.8 | 0.0 | -2.0 | -4.2 | 11.8 |
| **Case 2** | | | | | | | | | | | | | | | | | | | | | |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **60.0** | **35.0** | **0.0** | 19.6 | 1.0 | 8.8 | 4.2 | | 1.0 | 11.8 | 6.9 | | 0.0 | 2.9 | 2.7 | 0.0 |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **60.0** | **24.5** | **10.5** | 19.6 | 1.0 | 8.8 | 4.2 | | 1.0 | 11.8 | 4.8 | 2.1 | 0.0 | 2.9 | 0.6 | 2.1 |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **60.0** | **17.5** | **17.5** | 19.6 | 1.0 | 8.8 | 4.2 | 0.0 | 1.0 | 11.8 | 3.4 | 3.4 | 0.0 | 2.9 | -0.8 | 3.4 |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **60.0** | **10.5** | **24.5** | 19.6 | 1.0 | 8.8 | 4.2 | 0.0 | 1.0 | 11.8 | 2.1 | 4.8 | 0.0 | 2.9 | -2.1 | 4.8 |
| 14.0 | 7.0 | 63.0 | 30.0 | 0.0 | **5.0** | **60.0** | **0.0** | **35.0** | 19.6 | 1.0 | 8.8 | 4.2 | 0.0 | 1.0 | 11.8 | 0.0 | 6.9 | 0.0 | 2.9 | -4.2 | 6.9 |

The compressive strength test was performed according to the procedure described in section 3.3.2.3 and compressive strength was calculated using Equation 3-1. The data was analyzed to identify the effect of adding rubble toward the soil concrete strength. Figure 3-16 shows the compressive strength variation with the rubble for the first case.

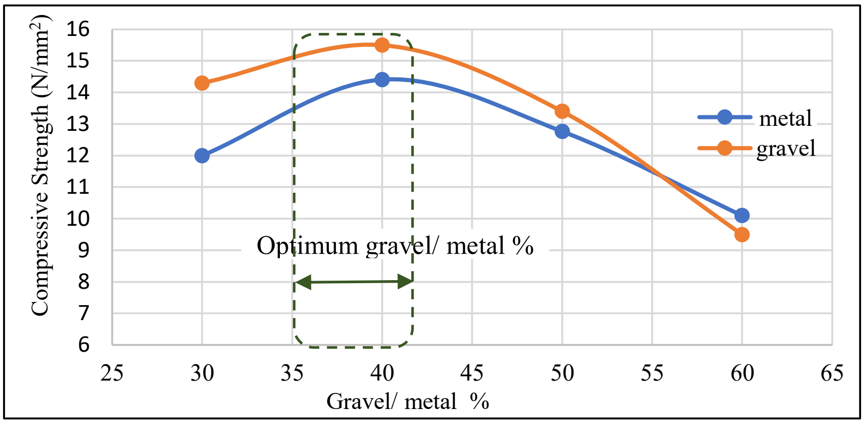



*Figure 3-16: Compressive strength variation with fully replacing the gravel with metal*

This result shows that the compressive strength reached its optimum value when the rubble percentage was in between 35% -40 % which was the same as the gravel percentage. But the compressive strength was lesser than the soil concrete with a minimal amount of gravel.

Next, the second case results were analyzed as shown in Figure 3.17. The partial replacement of gravel by rubble particle is effective but the replacement percentage was restricted to 8% to 14% of metal amount. Further increment of rubble was insignificant.

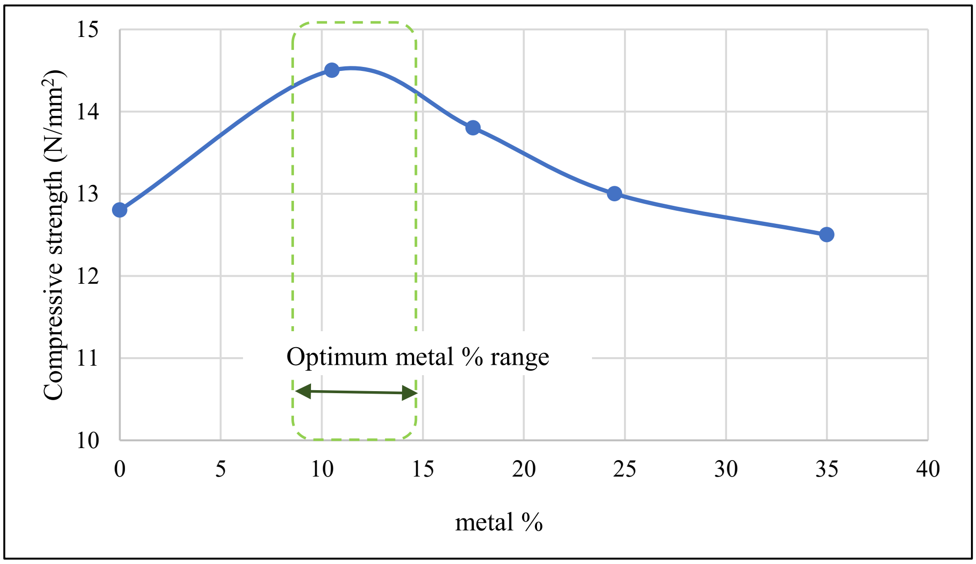



*Figure 3-17: Compressive strength variation with partial replacement of gravel with metal*

According to the overall results obtained in both steps, it was concluded that the addition of the rubble will not influence the soil concrete compressive strength at a significant level when considering the other factors of metal as raw material. However, if it is required, rubble could be added to a maximum of 10%. Therefore, it was decided to continue future experiments by only developing the existing soil without adding any rubble.

Overall, the two parts mentioned above described the way to influence soil consistency on soil concrete strength (section 3.3.2 & section 3.3.3). Since water and cement content affects concrete quality, the next section will look at how these variables affect soil concrete strength.

## 3.4. Identifying the impact of water content on compressive strength

The workability and the strength of cement concrete are well dependent on the water cement ratio. Thus, excess water may cause to segregate the aggregate. However, to complete the hydration process of cement, it is important to have a sufficient amount of water. Therefore, to find out the correct amount of water for the mixing of concrete is vital. This section will describe the experiments which were done to determine the impact of the water content on the compressive strength of soil concrete.

First, the soil was developed to have optimum fine and gravel content. In this experiment series, the soil was developed to have 5% fine and 35% gravel and 60% sand. Developed soil was mixed with different water amounts. The standard size (150 mm x150 mm x150 mm) cubic specimens were cast using the steel moulds. Based on the primary results obtained in section 3.3.1, the soil was mixed with five different water contents starting from 3000 ml up to 4000 ml increasing gradually by 250ml.Since the cement content also affected the properties of concrete, this determination was done for changing the cement content. Cement content was changed from 10% - 20% at 2% intervals. The specimen preparation plan for this investigation is indicated in Figure 3-18 and Table 3-9 which shows the designed mix proportions.

| Mix | Water | No. of cubes | Specimen code | Total no of Specimen |
|---|---|---|---|---|
| Mi | Wj | Xk | MiWjXk | |
| i= 1,2,3,4 & 5 | j= 1,2,3,4 & 5 | k= 1,2 & 3 | Eg. $M_3W_2\ X_1$ | 75 |

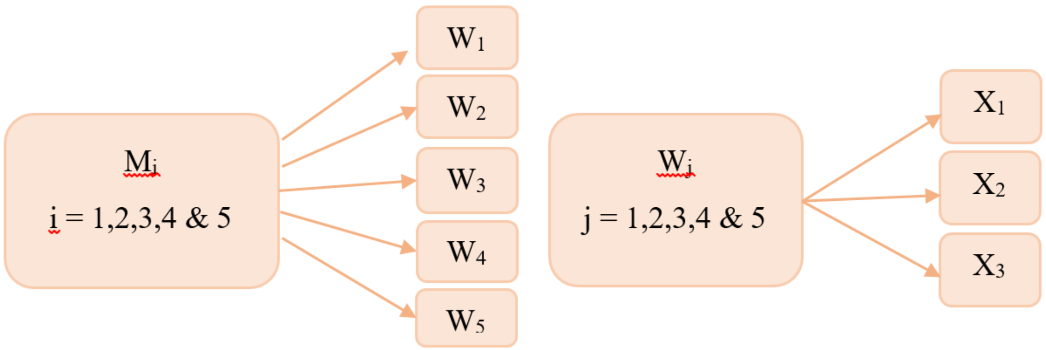



*Figure 3-18: Soil concrete preparation plan*

*Table 3-9: Soil concrete mix proportions*

| Mixture | Cement | Gravel | Sand | Fine |
|---|---|---|---|---|
| M1 | 10 | 35 | 60 | 5 |
| M2 | 14 | 35 | 60 | 5 |
| M3 | 16 | 35 | 60 | 5 |
| M4 | 18 | 35 | 60 | 5 |
| M5 | 20 | 35 | 60 | 5 |

The soil concrete mixing and specimen casting process are the same as described in section 3.3.2.3. Specimens were de-moulded after 24hrs from the casting. Until the time of the testing, all specimens were cured in the same circumstances. To obtain the data matrix, a total of 75 cubes were cast according to the sample preparation pattern. All specimens were checked for dry compressive strength after 28 days of curing. According to the procedure described in section 3.3.2.3 the compressive strength of all samples was determined in this context. Three samples from each prepared soil concrete mix were oven-dried for 24 hours at a constant temperature (105 °C) to determine the moisture percentages. Moisture percentage for all the mix proportions were calculated using Equation 3.2

$$\text{Moisture content} = \frac{\text{Wet Soil wt.- Dry Soil wt}}{\text{Dry Soil wt}} \times 100$$ *Equation 3-2*

The behaviour of soil concrete compressive strength with different moisture contents for different cement percentages was analyzed. The variation of compressive strength was graphically represented in Figure 3-19. The results indicate that the increase in the water content causes a decrease in the compressive strength, linearly at a constant rate for all cement percentages. The gradient (m) of each graph gives equal values with a negligible difference for all the selected cement percentages. Thus, the following Equation 3-3 could be derived to convert the compressive strength when mixing with any cement content and any water content value. This finding will be used in the future, to convert the experimental compressive strength value obtained in any soil concrete mix with any water content value to the compressive strength of the required water content.

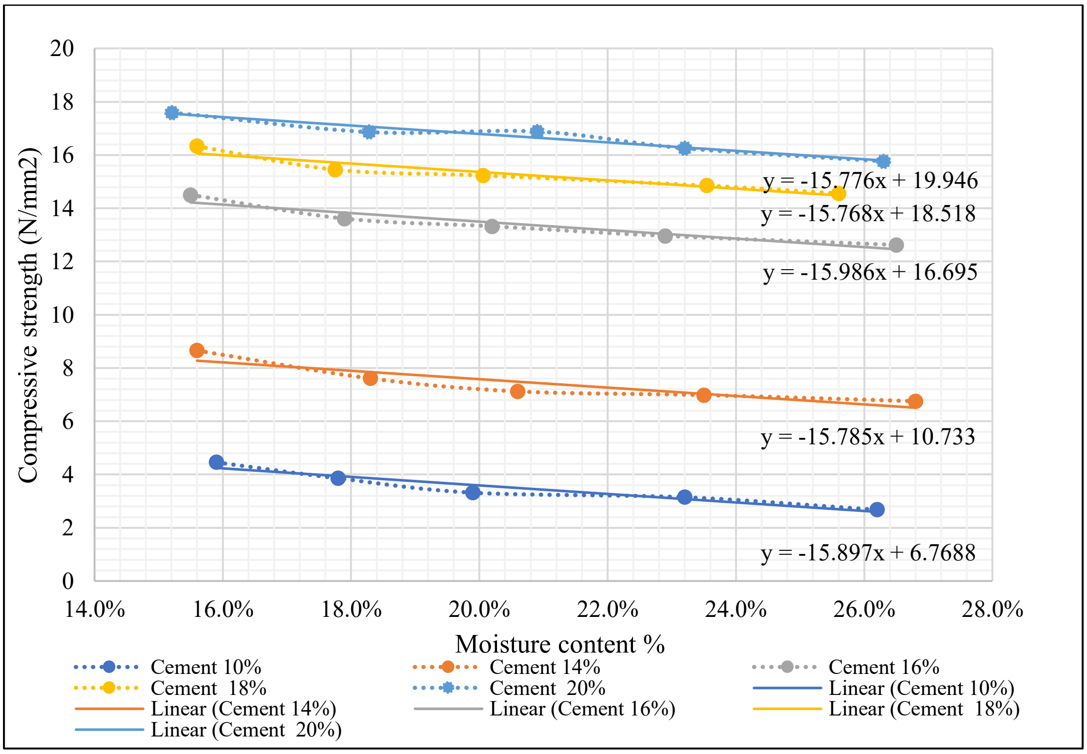



*Figure 3-19: Variation of soil concrete compressive strength with water content*

$$\boxed{Y \quad = mx + c}$$ *Equation 3-3:*

The 150 mm x 150 mm x 150 mm cubes were used to analyze the compressive strength of soil concrete in all the above sections. Moulds in various sizes and shapes are available and are used in the building industry to test the compressive strength of cement concrete. The impact of the specimen size and the shape on soil concrete compressive strength is an important consideration when choosing a sample size for the test. As a result, the next tests will assess the impact of sample size and shape on the compressive strength of soil concrete.

## 3.5. Identifying the effect of specimen's size and shape on compressive strength of soil concrete

150 mm x 150 mm x 150 mm standard cubes are usually used to determine the compressive strength of the mud concrete [228]. Previous studies can be found on the effect of size and shape for conventional cement concrete (i.e. Cement: fine aggregate: coarse aggregate) and cement concrete with several other constituents such as glass fiber, admixtures, etc. Cross sectional shape of the specimen and mix proportions were considered mainly as the two effective factors for compressive strength of cement concrete. Further, there are advantages of using smaller specimens, which affect the test results such as ease of handling, likelihood of accidental damage, cheaper moulds, lower capacity testing machine and type of machines used [229] [230]. According to authors in [231], the compressive strength of materials such as concrete, stone, etc. is a function of the test specimen's dimension [231]. The size of the test specimens is prescribed in different standards, but occasionally more than one sizes are permitted. In the case of cement concrete, the compressive strength test specimens vary from one country to another. There are many previous researches to compare the compressive strength of cement concrete with different sizes of cubic, cylindrical, and prismatic specimens. Table 3-10 summarizes the standard specimens used in different countries.

*Table 3-10: the standard specimens used in different countries*

| Specimen | Country | Sources |
|---|---|---|
| 150mm x 300mm cylinders | Unite state, Canada, France, Australia, America, South Korea, Canada, Norway | [232] [233] [234] [235] |
| 150mm cubes | United Kingdom, Germany, Britain, Europe, Norway | [232] [233] [235] |
| both cylinders and cubes<br>200mm cube, 150mm x 300mm cylinder<br>300mm cubes, 150mm x 300mm cylinder | Turkey<br>Old Turkish standard<br>New Turkish standard | [232] |
| 150x150x600 mm Prismatic specimen | Russia | 8[234] |

Table 3-11 summarizes some of the studies regarding the effect of shape and size of the specimens on the compressive strength of cement concrete. Many researches concentrated on the size and shape effect of the specimens and most of them found that the strength decreases with increase of the specimen size [233] [234] [235] [236] [237] [238]. Authors in[236] established that the ratio of cube to cylinder compressive strengths decreases with an increase in the level of concrete strength[236]. In [239] [20], the ASTM C39/C39M-03 is intended, cylindrical concrete specimens as the standard test specimen to determine the compressive strength. Authors in [237] proposed equation 1 (Table 3:11) to show the relationship of compressive strength of a concrete specimen and its size and shape. Authors in[238] suggested equation 2 (Table 3:11) to convert the compressive strength[238]. Both considered the conversion factor as a function of the specimen's volume (v), aspect ratio (d/h), height (h), maximum lateral dimension (d), which were considered the main parameters for compressive strength. The effect of the specimen's size is stronger for low strength concrete and it was more notable for specimens with less slenderness ratio. The effect of the specimen's size for cubes and prisms is stronger than for cylinders[232] [240]. Equations (3), (4) and (5) (Table 3:11)  were suggested by authors in [235], to obtain compressive strength relationship of general cubes with standard cubes, compressive strength of prisms with standard cubes and of general cylinder to standard cylinder respectively[235]. Authors in [241] developed equation 6 (Table 3:11) to relate the compressive strength of general cylinder with the standard cylinder's [241]. According to authors in [240], the effect of the shape is unimportant and the effect of the size is noticeable in static compressive strength, but it is insignificant in dynamic tests. Further, they reported that the effect of the specimen's size and shape on concrete static test is independent of concrete's grade[240]. Moreover, the variation of compressive strength of 100mm cubes and 150mm standard cubes were in the range of 5-6% and the strength of smaller cubes was higher than that of larger cubes [231] [232].

However, hardening mechanical properties of soil concrete in different proportions are dissimilar to cement concrete, the different size and shape effects too can be expected. However, it was found that the effects of specimen shape and size on the compressive strength of soil concrete are still not identified. Therefore, this section was forecast to predict the best size and shape of test specimens to determine the compressive strength of soil concrete and identify the relationship between compressive strength and specimen size and shape on soil concrete.

Materials used and method of mixing were done according to the procedure described in section 3.3.2.3. Cylindrical and cubical steel moulds which are commonly used and available at the university laboratory were selected. The dimensions and the shapes of the selected specimens are shown in Table 3-12 and Figure 3-20.  Five different soil concrete mixes are shown in Table 3-9 in section 3.3.4. (M1-M5) were made while keeping the water content at a constant level. All samples were cast in manual compaction while cylindrical samples were cast by compacting manually in three layers. According to the sample preparation plan shown in Table 3-13, 135 numbers of specimens were cast to achieve the data matrix.

*Table 3-11: the studies of the effect of shape and size of the specimens on the compressive strength of cement concrete*

| Equation | Relationship | Relationship between | Resources |
|---|---|---|---|
| **1** | $\frac{P}{P6} = 0.56 + \frac{0.697}{\frac{v}{6\text{h}d} + \frac{\text{h}}{d}}$ | Strength of cylindrical, cubical or prismatic specimen to strength of 150mm cube | [237] |
| **2** | $\frac{fcy}{fc'} = 0.8 + \frac{0.4}{\sqrt{1 + \frac{\text{h} - d}{50}}}$ | Strength of cylindrical specimen to strength of the standard cylinder | [238] |
| **3** | $fcy = \frac{0.49fc'}{\sqrt{1 + \frac{d}{2.6}}} + 0.81fc'$ | Strength of cylindrical specimen to strength of the standard cylinder | [235] |
| **4** | $fcu = \frac{1.17fc'}{\sqrt{1 + \frac{d}{2.6}}} + 0.62fc'$ | Strength of cube specimen to strength of the standard cylinder | [235] |
| **5** | $fpr = \frac{1.02fc'}{\sqrt{1 + \frac{d}{2.6}}} + 0.52fc'$ | Strength of prisms specimen to the strength of the standard cylinder | [235] |
| **6** | $\frac{fc}{fcu15} = 1.317 - \frac{0.1694}{\frac{v}{b15\text{h}d} + \frac{\text{h}}{d}}$ | Strength of cylindrical, cubical or prismatic specimen to strength of 150 mm cube | [241] |

*Table 3-12: Size and shapes of selected moulds*

| **Type** | **Shape** | **Dimension (mm)** | **Aspect ratio (h/d)** | **Lateral dimension d (mm)** |
|---|---|---|---|---|
| Cube | Square | 100x10x100 | 1 | 100 |
| Cube | Square | 150x150x150 | 1 | 150 |
| Cylinder | Circle | Φ 150 x 300 | 2 | 150 |

*(a ) Cylindrical specimens* *(b) 150mm cubical specimens* *(c )100mm cubical specimens*

*Figure 3-20: Steel mould used for casting*

*Table 3-13: Sample preparation plan*

| Mix(Mi = 1,2,3,4,5) | | | |
|---|---|---|---|
| **Age of test (days)** | **No. of specimens** | | |
| | **150 mm cube** | **100 mm cube** | **150 x 300 mm cylinder** |
| 7 | 3 | 3 | 3 |
| 14 | 3 | 3 | 3 |
| 28 | 3 | 3 | 3 |
| | 9 | 9 | 9 |
| Total | 27 | | |
| Total no of specimens x Five mixes = 27x 5 = 135 | | | |

Specimens were removed from the moulds after 24 hours from the casting and all specimens were exposed to the curing process under the same conditions before the time of the examination. After curing for 7 days, 14 days, and 28 days, specimens were tested for dry compressive strength. Sample preparation and prepared specimens are shown in Figure 3-21 and Figure 3-22. In addition, three samples from each mixture were oven dried for 24 hours at a constant temperature (105 °C) to determine the moisture content of concrete mixes.

*(a ) Cylindrical specimen* *(b) 150mm cubical specimen* *(c )100mm cubical specimen*

*Figure 3-21:Speciment preparation*

*(a ) Cylindrical samples* *(b) 150mm cubical samples* *(c )100mm cubical samples*

*Figure 3-22: Prepared specimens*

In this step, specimens were tested for 7days, 14 days, and 28 days. The tests were done according to the same procedure using the same machine described above in section 3.3.2.3. The top surface of the cylinder finished with a trowel during the casting was insufficient smooth and not plane enough to test, according to ASTM C 617 [242]. Therefore, the cylindrical specimens were ground to level the surface as shown in

Figure 3-23 before the testing, and Figure 3-24 shows the few steps of the specimen's testing.

*Figure 3-23: Top surface of cylindrical specimens prepared for testing*

*(a ) cubical sample* *(b) cylindrical sample*

*Figure 3-24: Compressive strength testing procedure*

The moisture percentage of each concrete mixture was calculated using the Equation 3-2. The results obtained are tabulated in Table 3-14. Compressive strengths were calculated using Equation 3-1. The results reveal that, while the added water content of concrete remains unchanged during mixing, the moisture percentages of dry mixes could vary. As a consequence, the compressive strength effects could be subjected to minor moisture content variations. According to the results obtained in section 3.3.4, the compressive strength depends on the moisture percentage. Therefore, the compressive strength values of all the mixes were recalculated to a common moisture content value, which is 19% using Equation 3-3.

*Table 3-14: Observed moisture percentages*

| Mixture code | Moisture % |
|---|---|
| M1 | 19.8 |
| M2 | 19.1 |
| M3 | 18.9 |
| M4 | 18.2 |
| M5 | 19.4 |

Compressive strength variations with age into different shapes and sizes for the selected mixes were analyzed and represented graphically in Figure 3-25. Results presented that the compressive strength increased with the age. More than 50% of 28 days' strength is achieved in the first 7 to 10 days and with time, the strength variation shows slow increment.

The variation of compressive strength with the cement percentage into different shapes and sizes for the selected mixes were then analyzed and graphically represented in Figure 3-26. These results indicate that the compressive strength could increase with the increase of the cement percentage. However, the rate of this increase was higher for lower cement percentages (10% to 14%) and was less for high cement percentages (14% to 20%). Further, as a whole, it could be concluded that the pattern of the compressive strength variation is uniform for all the specimen shapes and sizes which were tested. The cylindrical-shaped specimens showed lower strength than the cubes in all mixes. Moreover, the difference in compressive strength at 28 days for both 100mm and 150mm cubes was found negligible, regardless of the cement content. This fact was supported by O. Arioz *et al (2009)* too, for cement concrete [232]. Another important finding was that raising the cement percentage beyond 16% to 18% has negligible impact on the 28 days compressive strength. The specimens of 16% cement have the highest strength. Thus, increases in cement percentage do not have a significant impact on the strength of soil concrete.

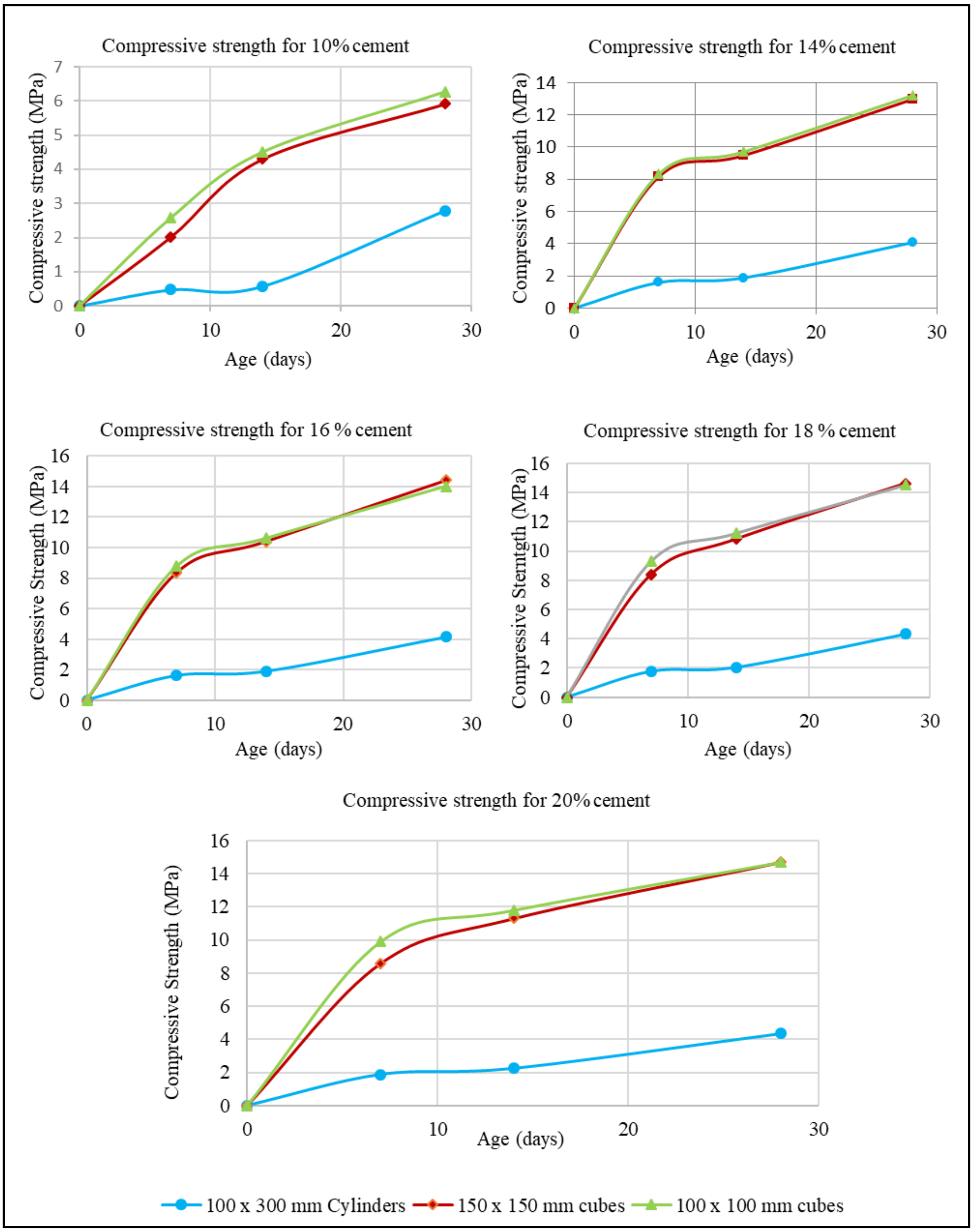



*Figure 3-25: Compressive strength variation with age for different mixtures*

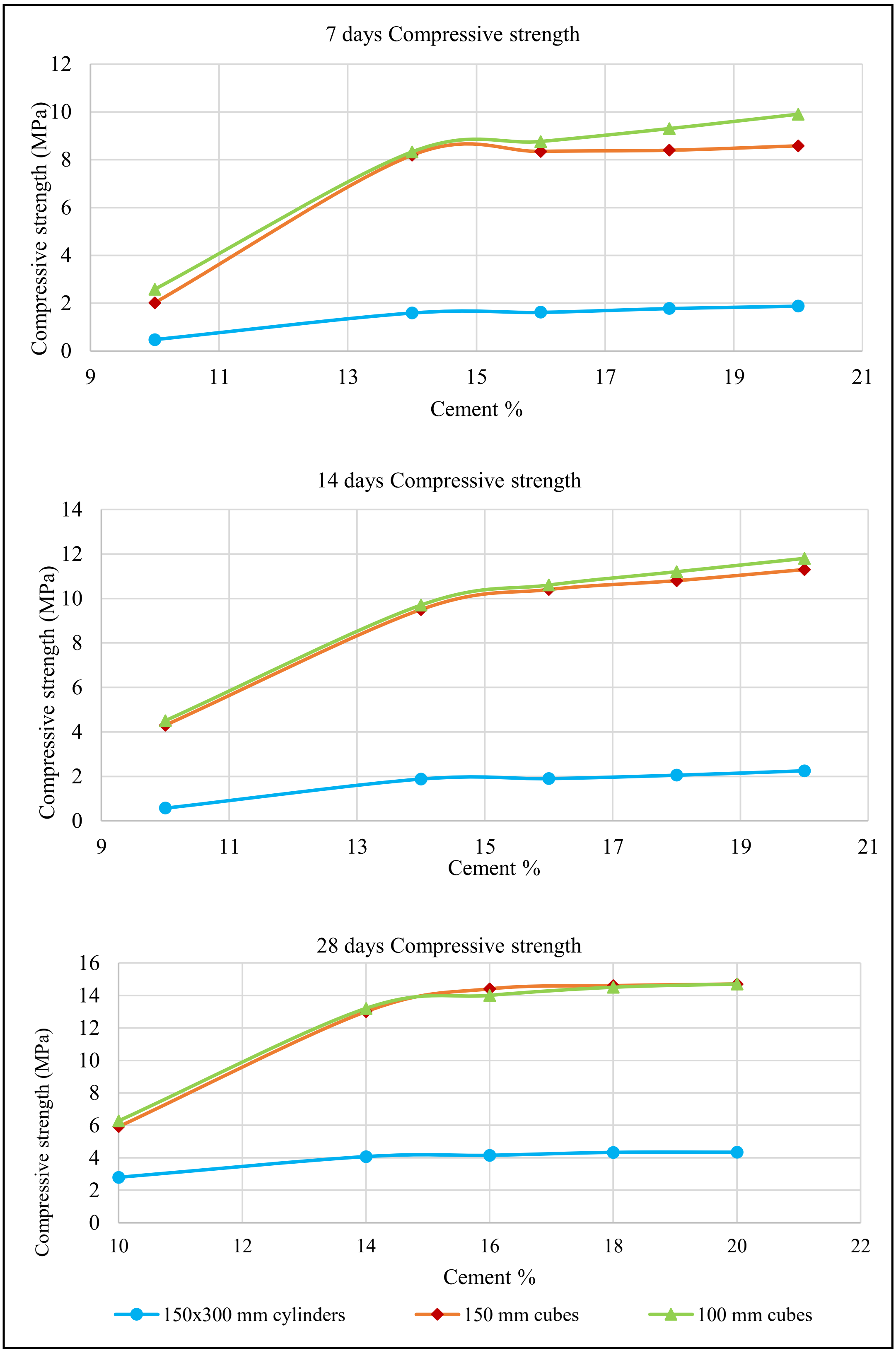



*Figure 3-26: Compressive strength variation with cement % for different size and shape of specimens*

### 3.3.2.6. Relationship of compressive strength into different sizes and shapes of the specimens

The relationship of compressive strength of different size and shape specimen to the compressive strength of 150mm cubes were generated. The results revealed that the ratio between 28 days compressive strength of cubes in dimensions 100 x 100 x100 mm ($fcu_{100x100x100}$) and the cubes in dimensions 150 x 150 x 150 mm ($fcu_{150x150x150}$) (i.e. $\frac{(fcu(100x100x100)}{(fcu(150x150x150)}$) was between 1.05 and 1.09, and the average of this ratio was 1.6. The same ratios for 7 days and 14 days' strength, were found as 1.13 and 1.10 respectively. These results indicate that the effect of specimen size for the above two sizes of the cubes had decreased with age.

The ratio of 28 days compressive strength of 150 x 300 mm cylinders ($fcy_{150x300}$) in to 150x150x150 mm cubes ($fcu_{150x150x150}$) (i.e. $\frac{(fcy(150x300)}{(fcu(150x150x150)}$) was between 0.17 and 0.21, and the average of this ratio was 0.2. For 7 days and 14 days, the same ratio was found as 0.22 on average. These results indicate the same effect as above were applicable for the specimen's shape too.

In literature, the cube's compressive strength of cement concrete is found as 1.25 times the compressive strength of the cylinder, but the actual strength relationship of the two shapes (cube and cylinder) depends on the strength level and the moisture content of the concrete during testing [230]. In addition, 1.2 factor has been used by BS1881: part 120; BSI 1983 to convert the cylindrical specimen's strength into cube's strength in normal cement concrete [243]. The correction factor, on the other hand, depends on the degree of concrete strength, with high strength concrete being less influenced than low strength concrete [244]. The findings of this section concludes that 150 mm soil concrete cube's compressive strength is 0.94 times the compressive strength of the 100 mm cube. 150 cube's compressive strength of soil concrete is 5 times the compressive strength of the cylinder. The pattern of the compressive strength variation was uniform for all the soil concrete specimen shapes and sizes which were tested and the cylindrical-shaped specimens showed lower strength than the cubes in all mixes.

#### 3.3.2.7. Failure pattern of different specimen shapes

The failure pattern of cubical and cylindrical specimens of soil concrete was compared with the failure pattern of cement concrete. During the initial loading stage, cracks developed longitudinally, and when the applied load increased, the initial cracks had sharply propagated from the top to the bottom till the failure of the specimen. When increasing the load on the cubical specimens, the cracks were slowly propagated and decreased (due to the effect of shear) toward the centre of the cube. The centre core leaves relatively undamaged, following the 'non-explosive' failure pattern [237], [245]. According to the Authors in [237], the failure pattern of these cylindrical specimens could be defined as a cone and spilled failure [237]. The failure pattern comparison is shown in Figure 3-27.

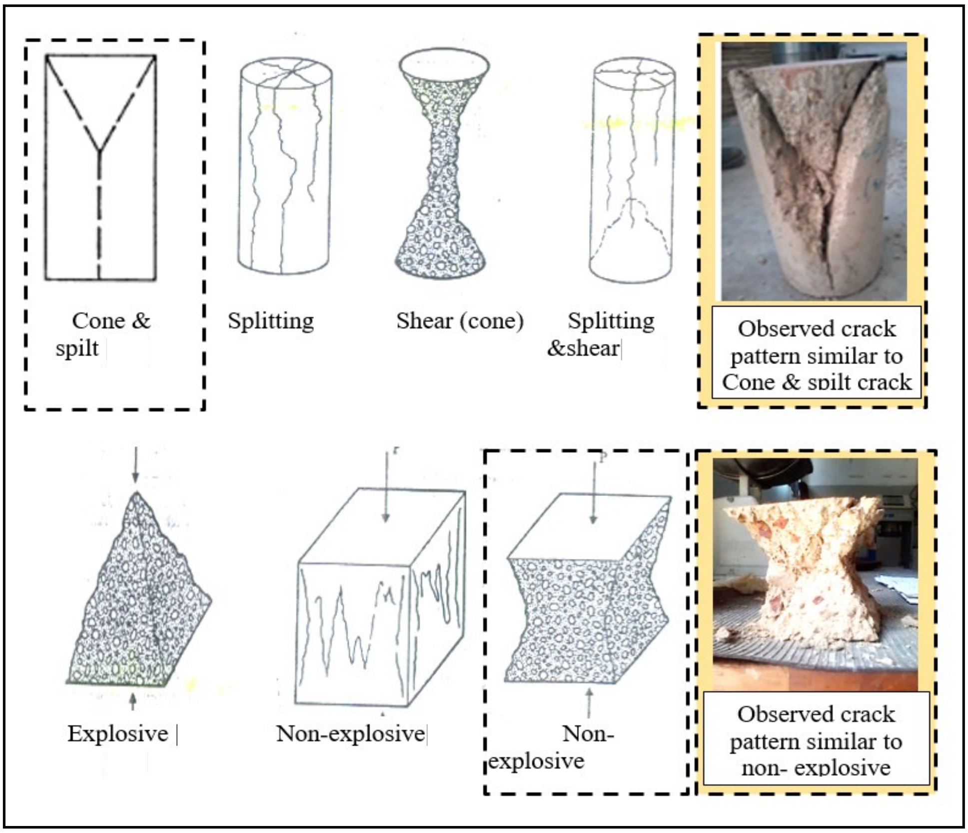



*Figure 3-27: Comparison of failure pattern*

## 3.6. Shrinkage on soil concrete

Drying shrinkage could cause by a loss of moisture from the concrete. It occurs after the concrete hardens and continues for months and even years depending on the slab thickness and ambient conditions. This type of shrinkage is largely responsible for random cracking, and crack widths, of concrete floors. Concrete shrinkage is principally controlled by the shrinkage of the cement paste and the quantity and properties of the aggregates. More specifically, the shrinkage potential of a concrete mixture is established by: the water content, aggregate volume, aggregate size and gradation, and content of cement. The water content, aggregate gradation is already concluded for the requirement of soil floor base. Therefore, in this section, the shrinkage of concrete in different water content was analyzed

Since there is not any standard or research data available to determine the shrinkage for soil concrete, the standard test method for length change of hydraulic cement mortar and concrete (ASTM C 157/C 157M-03) [246] was used to determine the shrinkage of soil concrete. The procedure described in [247] was also taken as a reference.

Soil concrete with 16% cement content was mixed to determine the variation of drying shrinkage and wetting expansion with the water content. Standard size of 75 x75 x 225 mm prismatic samples were cast using plastic moulds. The test was conducted for five different water content values and in each mix 6 samples were cast. Three samples were used to determine the drying shrinkage and another three to determine the wetting expansion with time. Therefore, altogether thirty samples were cast. The plastic moulds and prepared samples are shown in Figure 3-28. The mould was carefully removed without disturbing the gauge stud after 24hrs from the casting. Just after the removal from the mould, the specimens were placed in lime saturated water maintaining temperature 23 $^0$C for 15 min to minimize the variation in length due to temperature change.

*Figure 3-28: Moulds and specimens for shrinkage test*

According to the procedure described in ASTM C 157/C 157M-03 [246], shrinkage measurements were taken. After 15 min inside the lime saturated water, specimens were removed one at a time, and wiped with a damp cloth. Then initial comparator readings and weights were taken immediately. After the initial comparator reading, part of the samples was stored in the drying room so that the specimens have a clear distance when air circulates. The other part of the specimens was immersed in lime saturated water. Then the comparator readings and weights of each specimen were taken after the period of 4, 7, 14, 28, 56, and 120 days. Figure 3-29 shows the comparator which could read up to 0.001mm for determining the length change and measurement of comparator reading. Before taking the comparator readings of specimens, the comparator reading of the reference bar was taken. The specimen was rotated slowly in the measuring instrument while the comparator reading was being taken. The minimum dial gauge reading was recorded while the dial gauge reading of the reference bar was checked often. The length change at any age was calculated using Equation 3-4 as a percentage in the nearest 0.001% report average to the nearest 0.01%

$$\boxed{L = \frac{(Lx\text{-}Li)}{G} \text{ X } 100}$$

*Equation 3-4:*

Where

L = Change in length in x age ,%

$L_x$= (Comparator reading of specimen at x age - Comparator reading of reference bar at x age) in mm

Li = (Initial comparator reading of specimen - Comparator reading of reference bar at that same time) in mm

G = Nominal gauge length = 250 mm

*Figure 3-29: Apparatus used to measurement of length change*

The length variation with time for different moisture percentages of soil concrete was graphically represented in Figure 3-30 and Figure 3-31. According to the results, it could be concluded that for all the water content percentages the length change became zero at 28 days for both drying and wetting conditions.

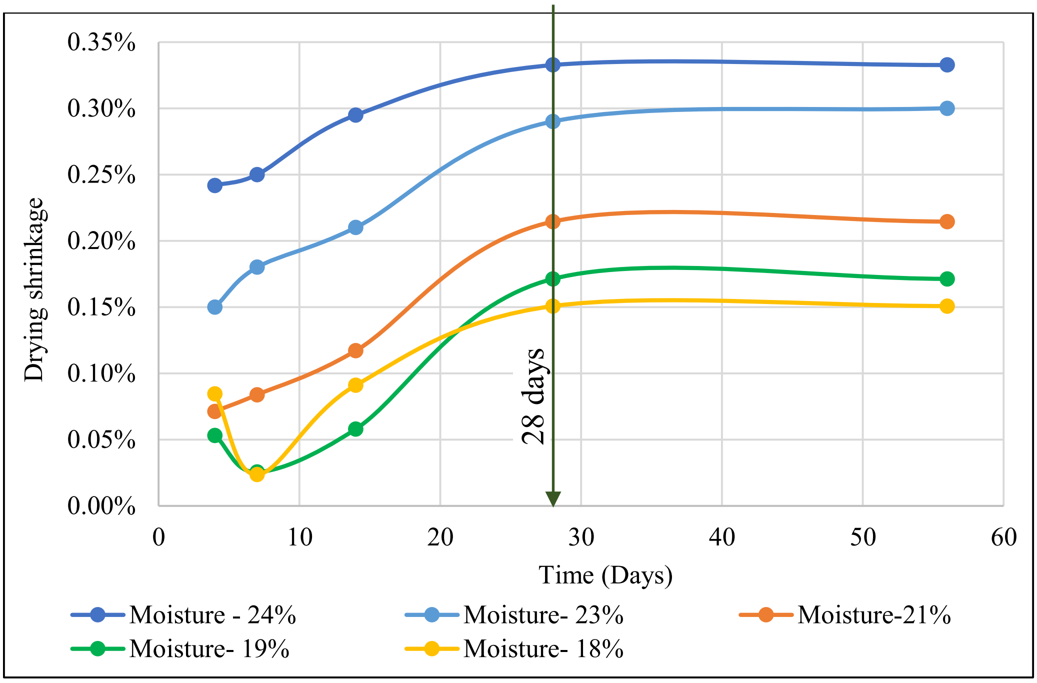



*Figure 3-30: Change in length – Drying shrinkage of soil concrete with different moisture %*

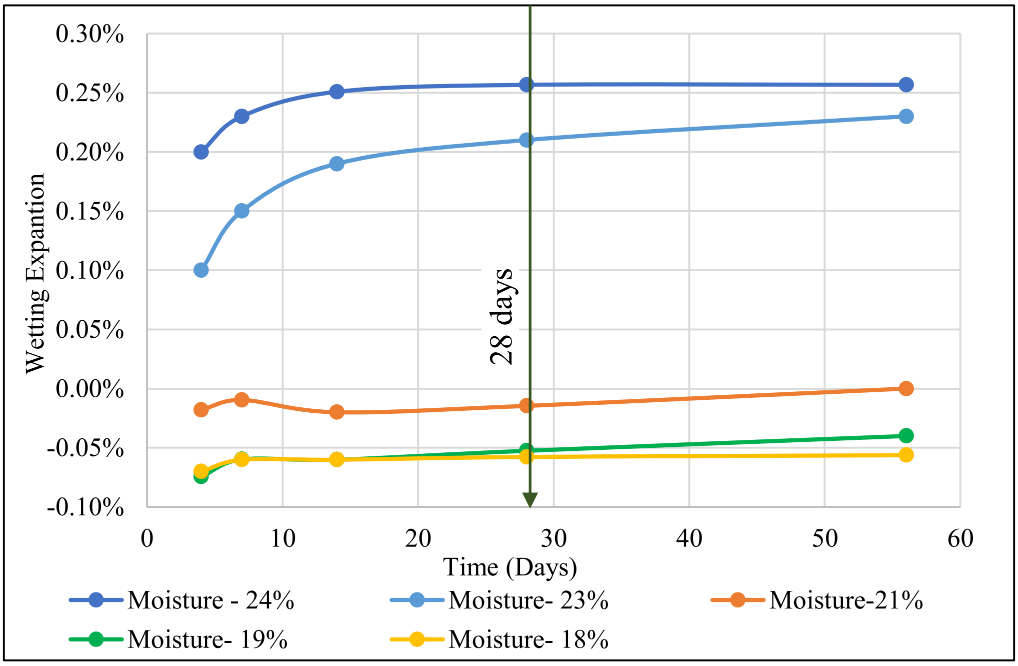



*Figure 3-31: Change in length – Wetting expansion of soil concrete with different moisture %*

The variation of length change with the moisture content of the soil concrete mix was shown in Figure 3-32. The results revealed that the water content affected both the drying shrinkage and the wetting expansion. Through the length, change became constant after 28 days while the value of change in length is higher for a higher percentage of moisture in soil concrete. It shows that the moisture content affects not only the strength and the workability but the shrinkage too.

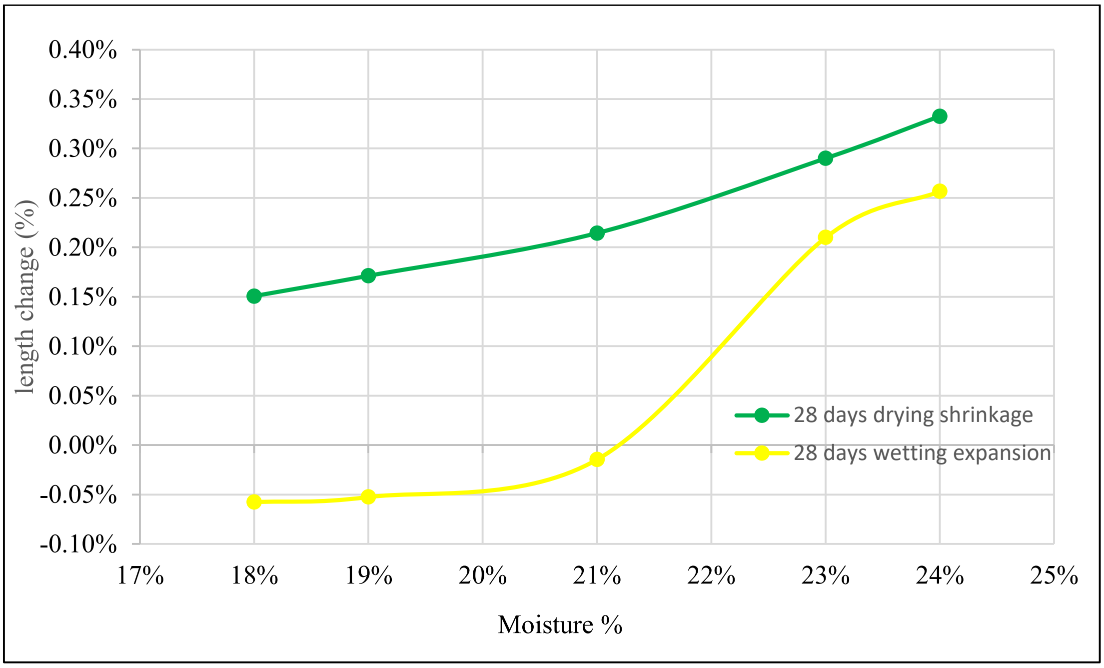



*Figure 3-32: The length change variation with the moisture % of soil concrete after 28 days from casting*

### 3.7. Summary

This chapter considered soil consistency that would be suitable for soil concrete in order to achieve the necessary strength of the floor base. Soil was used as the primary raw material, which was stabilized with cement and mixed with water to make the soil concrete. The experimentation sequence was carried out step by step. First, the amount of water required for a workable mix, the best soil gradation, and the best gravel size was investigated. During this part of study, the effects of cement percentage and water content on soil concrete strength were taken into account. Then, investigations were carried out to see whether another course aggregate could be used instead of gravel.

The relationship of strength on various sizes and shapes of specimens was explored while determining the proper size and shape of test specimens to determine the soil concrete compressive strength. The specimens' failure patterns were also found in this background. The shrinkage of the suggested soil concrete was assessed after the appropriate mix proportions for floor concrete was determined.

The water requirement for self-compacting soil concrete was identified as 16% -19% by dry soil weight with the aid of the floor table tests. The optimum fine particle (0.075 mm < fine < 0.425 mm) content found was 5%-10% and optimum gravel (0.475 mm < gravel < 25 mm) content was concluded at 30% -35%. The maximum gravel size for optimum strength was identified as 25 mm. The soil compressive strength was affected by the water content of the mix and it was identified that the strength decreases with the water content showing linear variation. This linear variation for all the cement content considered is with a constant gradient. Thus y= mx +c type of relationship was developed for variation of strength with water content of soil concrete.

More than 50% of 28 days' strength is achieved in the first 7 to 10 days and with time, strength variation shows slow increment and as cement concrete this soil concrete also shows the maximum strength at 28 days. When considering the strength variation with cement percentage it was identified that raising the cement percentage beyond 16% to 18% has a little discernible impact on compressive strength. The specimens of 16% cement have the highest strength. Increases in cement percentage do not have a significant impact on the strength of soil concrete.

According to the shrinkage test results, it was concluded that the length change became zero at 28 days for both drying and wetting conditions for all the water content percentages.

The mix proportions and properties of soil concrete were discovered in this chapter, and the next chapter will focus on the possibility of using chemical admixtures, which are commonly used in the cement concrete manufacturing industry, to improve the properties of soil concrete. The experiment sequences and results obtained will be presented in the next chapter.

# CHAPTER 4 : ADMIXTURES TO ENHANCE SOIL CONCRETE STRENGTH

## 4.1. General

Chemical, mineral or natural admixtures have been generally used in cement concrete to improve their properties. Soil concrete is a recyclable construction material made up of soil acting as a filler, cement as a stabilizer, and water as a binding agent. This innovation aims to introduce a long-lasting, durable flooring material with sustainable features. In terms of environmental sustainability, cement, which acts as a stabilizer in soil concrete, should be used minimally in this background.

The production process of soil concrete is fully manual and all ingredients are natural except cement. The use of cement could be considered the only disadvantage of this soil concrete as a sustainable material. Therefore, to find out the possibility of reducing the amount of cement is vital to address this main disadvantage. Furthermore, environmental impacts in production, and the cost are some of the main disadvantages that could be reduced by replacing a part of cement with admixtures. Cement concrete could transform itself to a high consistency and high workable level with a low w/c ratio using suitable and compatible admixtures to produce high perform concrete [230]. Therefore, the performance of soil concrete with admixtures was studied in this section. The principal approach, in this case, is to examine the compatibility of admixture which are used in cement concrete with soil and find out the most efficient combination of cement–admixture, enabling to obtain a maximum water reduction, better workability, and an acceptable rheology during the placement and the finishing stage of the soil concrete floor base.

Further, in the manufacturing of soil concrete, the water requirement has been much higher for the hydration of cement and maintain workability. This excessive water amount could enhance its self-compacting quality, which is capable of self-compacting without the need for any external compaction effort. However, according to the results obtained in section 3.3.4, the increase in water content causes to decrease the compressive strength. Therefore, it is essential to find a way to reduce the amount of water in soil concrete and enhance its workability while improving the strength.

In view of that, this effort is to investigate the behaviour of chemical admixtures with soil concrete and analyze the possibility of the use of these admixtures to enhance the soil concrete properties. The key objective of this step is to find the compatibility of soil concrete with different admixtures and to select an appropriate compatible admixture type and dosage to improve the properties of soil concrete. This chapter presents the experimental procedure and results obtained in investigating the use of chemical admixtures to maintain workability, reducing water and cement content, while improving the strength.

## 4.2. Material selection

Materials used are developed soil as described in section 3-1, 16% cement, and water. These basic ingredients of soil concrete were kept constant throughout this experiment series. Four types of admixtures (super-plasticizers (SP)) available in the current market were selected among several types of chemical admixtures. The selected admixture samples are shown below in Figure 4.1. The properties of selected admixtures and recommended dosage of manufacturers for the production of cement concrete are listed below in Table 4.1. First, the workability was analyzed to identify the effect of chemical admixture on soil concrete and then to find out the effect of chemical admixtures on strength characteristics. The slump tests and the flow table tests were performed to determine the workability and compressive strength tests were used to determine and evaluate the strength properties.


*Figure 4-1: Selected chemical admixtures*

*Table 4-1: Properties and recommended dosage of selected admixture*

| Admixture Code | Commercial Name | Information From Manufacturers | | | |
|---|---|---|---|---|---|
| | | **Appearance** | **Recommended Dosage** | **Recommended for** | **Standard** |
| AD1 | Rheobuild 561 | Dark brown liquid | 0.7 -1.2 L per 100kg cement | Easily flowing with free from segregation and having the same w/c ratio as that of a no-slump concrete without additive | ASTM C494 Type B, D & G, BS5075 Part 3 for high range water reducing admixture |
| AD2 | MasterEase 3703 | Light brown liquid | 0.2 -3.0 L per 100kg cement | Improve the quality of surface finishes, decreased shrinkage, and cracking Enhanced durability. | ASTM C494 Type F&G |
| AD3 | Brocrete S888 | Amber colored clear liquid | 0.6% - 1.5% of cement | | |
| AD4 | Brocrete S838 | Amber colored clear liquid | 0.5% - 1.1% of cement | | |

## 4.3. Workability test

The workability of soil concrete was measured to identify the effect of admixture on soil concrete. To assess the workability of cement concrete, a slump test is often used in this background. However, based on the knowledge gained from mixing soil concrete in the previous sections, it is understood that the clay and gravel in the soil concrete mix have a high degree of cohesiveness. As a result, a slump test, which is widely used to assess the workability of cement concrete, is an obvious way to get a better understanding of workability. As a result, the flow table test was conducted parallel to the slum test, and the flow diameter was measured as a workability indicator.

Though the proper initial water requirement for the workable mix was estimated in section 3.3.1, the optimum water requirement for the workable mix was determined again. Because the initial estimated optimum water content was found for soil concrete without considering the particle size distribution. Therefore, the soil concrete mixes were prepared with different water-cement ratios without adding the admixtures and measure the slump height and flow diameter as a control experiment. Then the soil concrete was mixed with selected admixture to different dosages. For this experiment series, four types of chemical admixtures were selected and were purchased from two main chemical suppliers in the Sri Lankan concrete industry.

This experiment was designed for mixes as shown below in Figure 4.2. For each mix a flow table test was performed for five different water content values and three times for each. (e.g. For Mix 1-1 flow table test for the water content of W1, W2, W3, W4, W5, and for one W value three times flow table tests). Therefore, one hundred and eighty (180) (4x3x5x3= 180) flow table tests were performed.

| **Admixture Type** | **Dosage** | **Water** | **No. of Flow table test** | **Specimen code** | **Total no of test** |
|---|---|---|---|---|---|
| ADi | Dj | Wk | Xa | (AD)iDjWkXa | |
| i = 1,2,3 & 4 | j = 1,2,3 | k=1,2,3,4& 5 | k= 1,2 & 3 | Eg.$(AD)_3D_1W_2\,X_1$ | 225 |

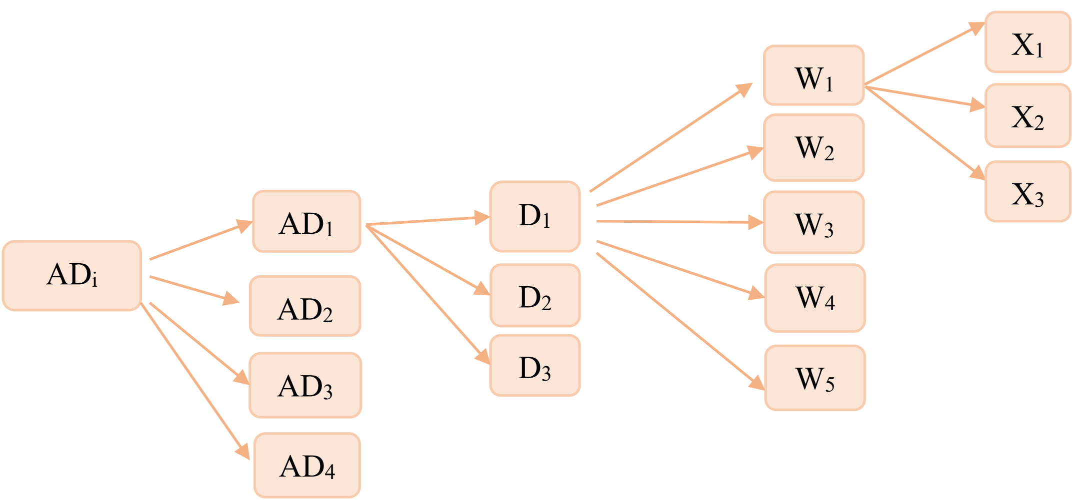


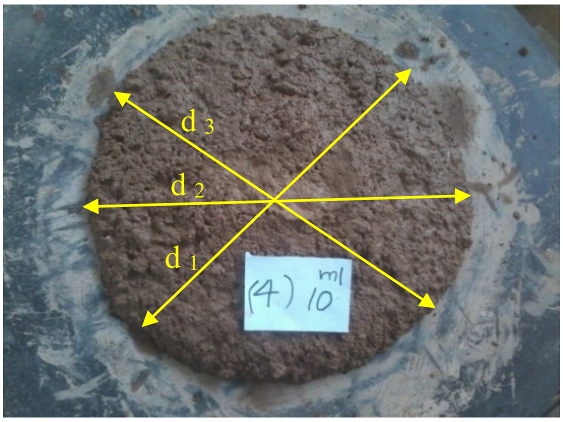

*Figure 4-2: Mix designation for workability test*

The admixture dosage range was selected according to the manufacturer's instruction given for cement concrete. For one test, 13 kg of developed soil is required. Therefore, the required amount of cement is 2.00 kg of cement (i.e. 16% by soil weight). The dosage of admixture is usually recommended according to the cement amount use. The calculation of the admixture dosage and dosage used for casting is shown below Table 4-2.

*Table 4-2: The calculation of the chemical admixture dosage and dosage used for casting*

<table>
<tr><th>Admixture Type</th><th>Admixture Dosage (ml) (D)</th><td rowspan="13">Eg: For AD1<br>Recommended dosage<br>= 0.7 – 1.2 l/100kg of cement<br>For 2.00 Kg of cement<br>= ( 0.7/100)*2.0 - (1.2/100)*2.0 l<br>= 14.0 -25.0 ml<br>Therefore,<br>select 15 – 25 ml</td></tr>
<tr><td>AD1</td><td>$D_1$- 15</td></tr>
<tr><td></td><td>$D_2$ -20</td></tr>
<tr><td></td><td>$D_3$- 25</td></tr>
<tr><td>AD2</td><td>$D_1$ – 5</td></tr>
<tr><td></td><td>$D_2$ -10</td></tr>
<tr><td></td><td>$D_3$ -15</td></tr>
<tr><td>AD3</td><td>$D_1$ - 7</td></tr>
<tr><td></td><td>$D_2$ -10</td></tr>
<tr><td></td><td>$D_3$- 15</td></tr>
<tr><td>AD4</td><td>$D_1$-10</td></tr>
<tr><td></td><td>$D_2$- 15</td></tr>
<tr><td></td><td>$D_3$- 20</td></tr>
</table>

The flow table test was performed according to the BS 1881 part 105 of 1984 [223], [224]. The Slump cone was placed on top of the floor table and was filled with three layers of a prepared soil concrete mix in one process. The excess mix from the test cone's top was removed after that. The cone was kept for 60 seconds and then raised in a single motion. Because of the cohesiveness of the material, the soil concrete mix did not disperse immediately. Therefore, 15 blows were applied within 15 seconds, and then the flow diameter was measured in three different directions as shown in Figure 4-3. Average flow Diameter (average) = $(d_1+d_2+ d_3)/3$ was noted in this occasion.


Average flow diameter (d) = $(d_1+d_2+d_3)/3$

Slump Height = h

*Figure 4-3: Floor table test procedure*

With the maximum spread of about 500 mm-600 mm diameter of a circle, while giving 15 constant blows, the proper workability of the mix could be achieved. Then the same procedure was followed for the soil concrete mix with different admixtures to different dosages. Consequently, three samples from each mix were oven-dried to calculate the moisture percentages of mixtures.

The results obtained from the flow table test for the control sample were first analyzed while the moisture content of all the mixtures was calculated using Equation 3-3. The variation of the flow diameter with the water content was analyzed and is graphically represented in Figure 4.4. During the mixing and casting process, it was observed that the mix is received in a workable condition when the flow diameter is in the range of 500-600 mm. According to the results obtained, it was concluded that to achieve a workable mix (i.e 500 mm - 650 mm flow diameter), the required moisture range was 16.5% - 18.6% for control samples which is soil concrete without admixtures.

Then the possibility to improve workability with chemical admixtures was analyzed. Figure 4.5 shows the flow table diameter variation for soil concrete mix with one type of admixture (type 1 (AD1) to different dosages as a sample presentation

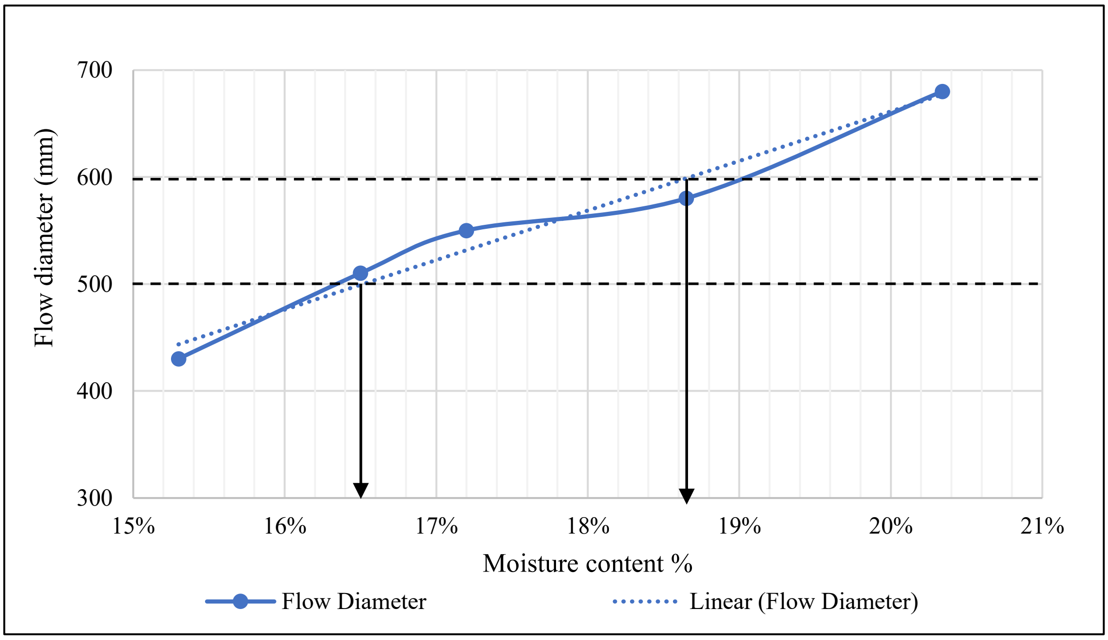



*Figure 4-4: Variation of flow diameter with moisture percentage – control sample*

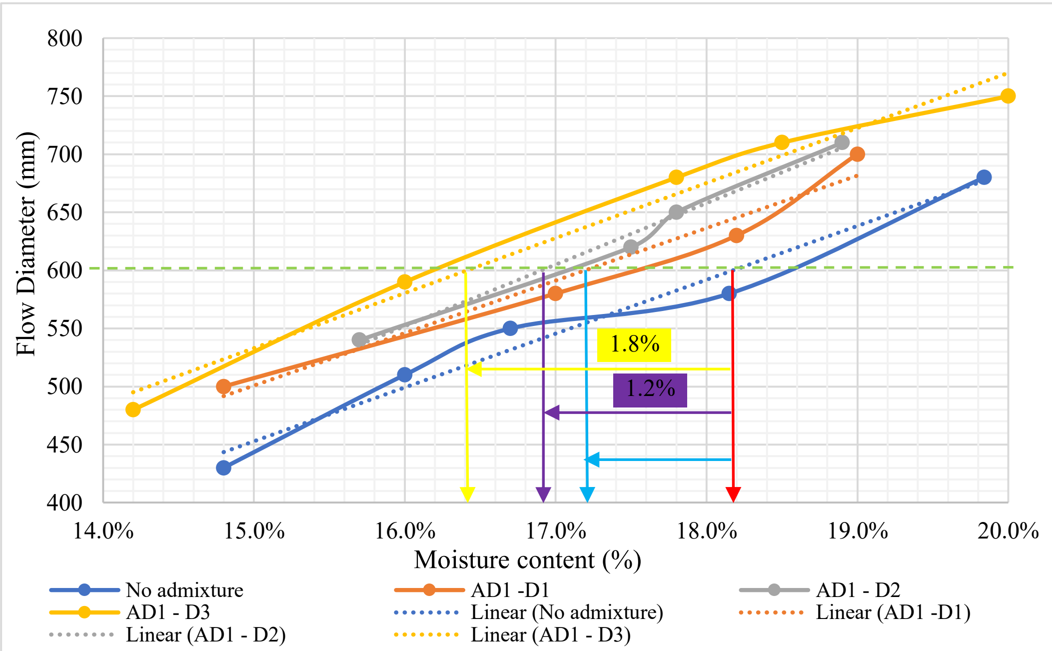



*Figure 4-5: Flow table diameter variation with the moisture content of mud concrete mixed with AD1*

According to the results, the flow table diameter shows that the addition of 15-25 ml (750 -1250 ml/100kg of cement) is effective on the way to reduce the water requirement of soil concrete to maintain optimum workability. Flow diameter variation shows a linear variation with a constant and an equal gradient. The variation of workability and the amount of water reduction ability of soil concrete with the admixture types was calculated. Table 4-3 shows the reduction in water due to the admixture by maintaining the workability which is 600mm flow table diameter.

*Table 4-3: Water reduction due to addition of admixtures*

| Admixture type | Dosage (ml/100kg of cement) | Reduction in water (%) |
|---|---|---|
| AD1 | 750 | 1.0 |
| | 1000 | 1.2 |
| | 1250 | 1.8 |
| AD2 | 250 | 1.1 |
| | 500 | 1.4 |
| | 750 | 2.0 |
| AD3 | 350 | 1.5 |
| | 500 | 1.8 |
| | 750 | 2.1 |
| AD4 | 750 | 1.0 |
| | 1000 | 1.4 |
| | 1250 | 1.8 |

The workability of the soil concrete mix with admixtures shows a linear variation for all types and all dosages of the admixture was the same as the control sample but at different levels. It shows that the soil concrete workability could be improved by adding chemical admixtures but on different levels for different admixtures. Therefore, it is recommended that the use of chemical admixtures could be useful to enhance the workability as it enhances the strength of soil concrete. However, the dosage must be decided by doing a trail mix.

### 4.4. Compressive strength test

From each workable mix (mix with flow diameter 500 mm -600 mm), three 150 mm cubes were cast using the same soil concrete mix with 16% cement and 16% moisture from dry soil weight to determine the compressive strength. In this case, five different water were used in this test. After 24 hrs from the casting, all cubes were demoulded and curing was done under unique conditions. Then, after 28 days from the casting, all the cubes were tested for compressive strength. The test was performed according to the procedure described section 3.3.2.3 using the same testing machine. The compressive strength of control samples is shown in Figure 4-6.

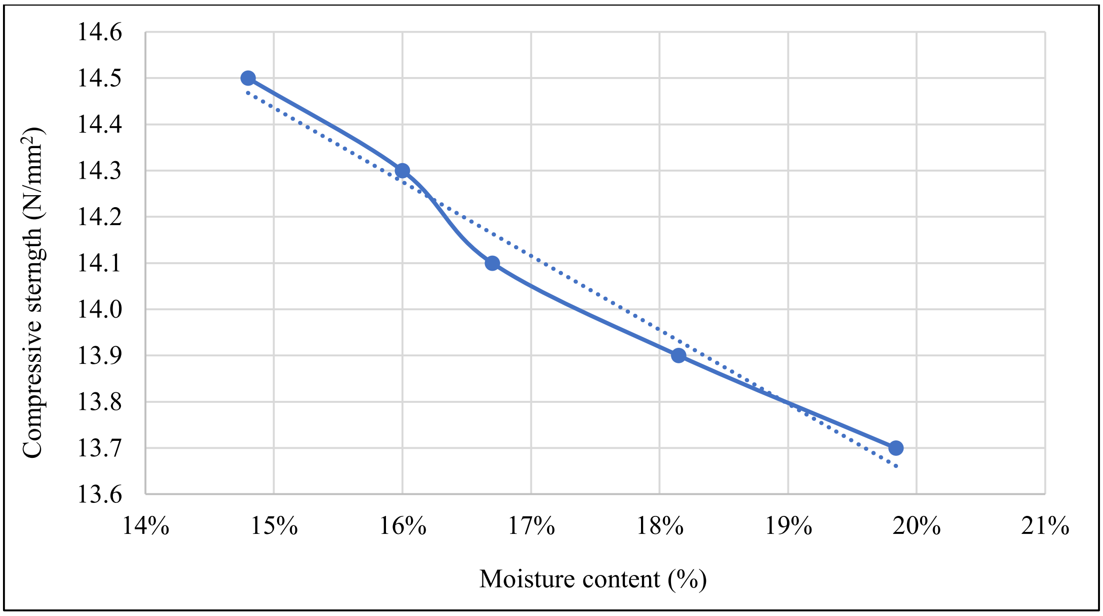



*Figure 4-6: The compressive strength variation with moisture content on control samples*

The compressive strength variation with the moisture content of the soil concrete without admixture shows a linear variation with a gradient of -16.00. With the adding admixture, the water requirement was reduced, hence compressive strength increment could be expected. The expected compressive strength due to the reduction of water content was calculated using the above linear variation for all cubes with admixtures. One specimen calculation as shown below was done to predict the strength increment with the reduction of moisture.

Gradient of the graph (m) $= -16.00$

Gradient (m) $= (y_2-y_1)/(x_2-x_1)$

$Y_2 = m\,(x_2-x_1) + y_1$

Where, $y_2$ - Expected strength at $x_2$ moisture content

$y_1$ - Strength at $x_1$ moisture content without admixture

$(x_2-x_1)$ - Reduction in water due to admixture

Eg: For cube cast with mix code $(AD)_1D_3$ (Admixture type 1 and dosage 25 ml)

Expected moisture reduction = 1.8%

At moisture content 15%, $y_1$ =14.5 N/mm$^2$

Expected strength $y_2$ = -16.00.x (-1.8%) +14.34

= 14.73 N/mm$^2$

Then, the cubes which were cast with admixtures were tested for compressive strength. These results indicate that the increase in strength is higher than the expected value and the strength increases in a linear manner with the admixture amount used in this context. The results are tabulated in Table 4-4. Figure 4-7 shows the compressive strength variation with admixture amount and Figure 4-8 shows the increase in compressive strength with the admixture amount. Therefore, it could be concluded that the addition of admixtures could improve the workability of soil concrete as well as the compressive strength which leads to reducing the cement requirement. The calculated cement requirement with admixture and reduction in cement percentage are graphically represented in Figure 4-9 (a) and Figure 4- 9 (b).

*Table 4-4: Predicted and observed compressive strength of soil concrete with selected admixtures*

| **Sample Code** | **Samples with Admixture (AD1)(ml)** | **Expected compressive strength (N/mm$^2$)** | **Observed average compressive strength (N/mm$^2$)** | **Strength increment (N/mm$^2$)** | **Cement reduction (%)** |
|---|---|---|---|---|---|
| A0 | No | | 14.34 | | |
| A1 | 3.00 | 14.20 | 15.1 | 0.9 | 1.0 |
| A2 | 5.00 | 14.40 | 15.5 | 1.1 | 1.5 |
| A3 | 7.00 | 14.60 | 15.9 | 1.3 | 2.0 |
| A4 | 10.00 | 14.63 | 16.1 | 1.52 | 2.2 |
| A5 | 12.00 | 14.73 | 16.3 | 1.60 | 2.4 |

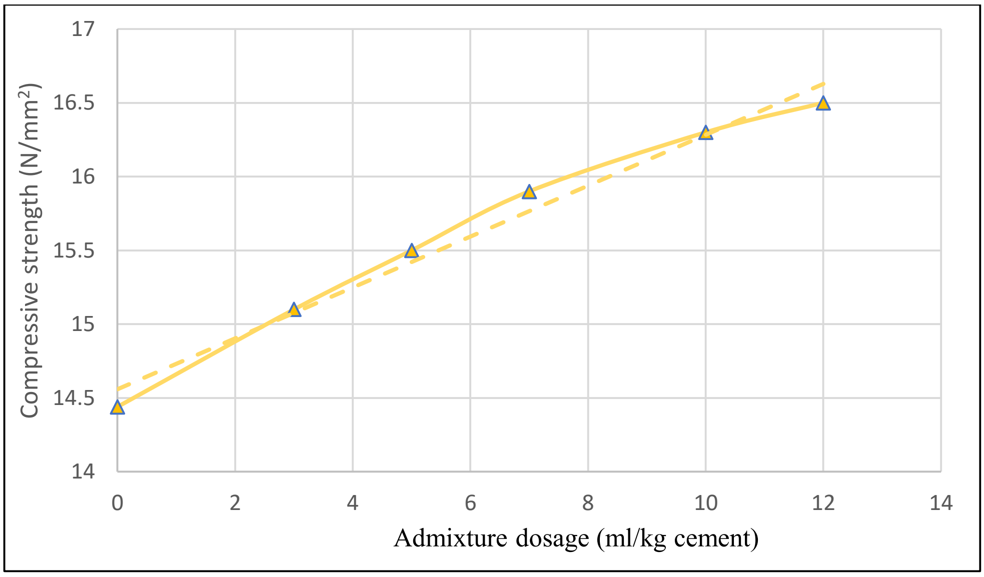



*Figure 4-7: The variation of compressive strength with the admixture dosage*

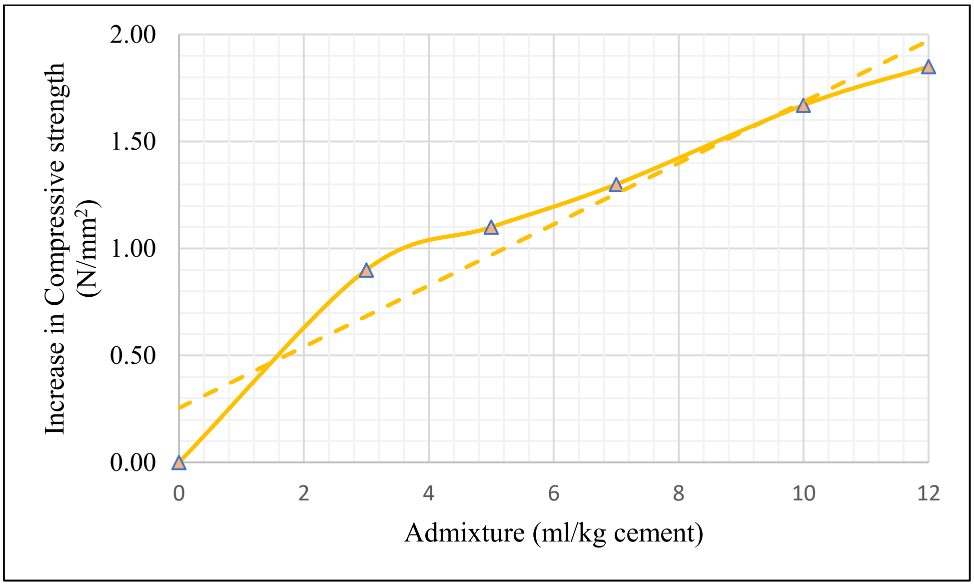


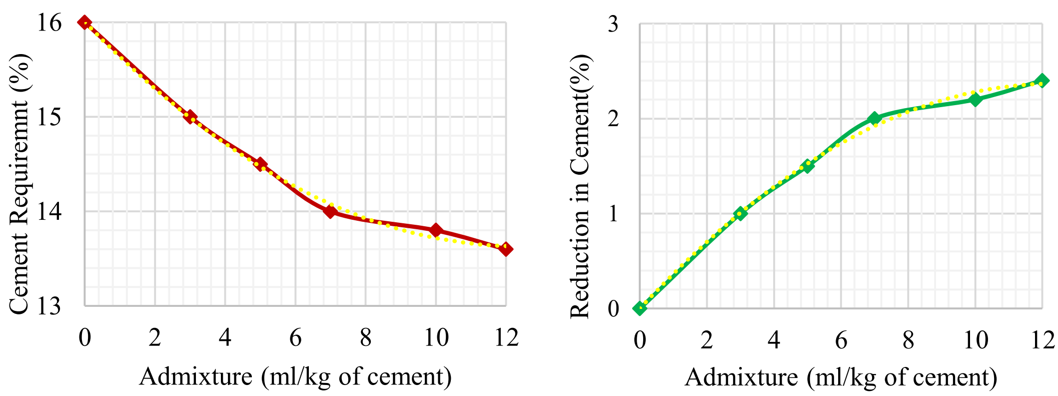

*Figure 4-8: Compressive strength increase with the addition of the Admixture*

Though the use of admixture increases compressive strength, it is limited due to its economic value. The cost analysis results are shown in Table 4-5. According to Figure 4-10 with the cost saving amount, the optimum admixture usage is 6-7 ml/kg of cement. Therefore, admixture dosage selection has to be done by considering its economic value. Though it is economically ineffective, it may show an environmental advantage in the reduction of cement. Accordingly, it is recommended to select the admixture type and dosage by considering all the relevant factors.

Next, the compressive strength variation of cement % for optimum admixture % (12 ml/kg cement) was examined. For this the same cubes were cast with a constant moisture percentage (18%) and constant admixture dosage by varying the cement percentage from 14% to 20%. The compressive strength variation is graphically represented in Figure 4-11. According to the results obtained, it was concluded that the addition of admixture increases the strength and the increment pattern which matched the strength increment pattern with the soil concrete strength variation without admixtures.

*Table 4-5: Evaluation of economical values of the admixture in soil concrete*

| **Admixture (ml/kg of cement)** | **Reduction in cement (%)** | **Cement requirem ent (%)** | **Cost for cement (Rs.)** | **Admixture amount (ml)** | **Cost of admixture (Rs.)** | **Total cost (Rs.)** | **Cost saving (Rs.)** |
|---|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 16.00 | 320.00 | 0.00 | 0.00 | 320.00 | 0.00 |
| 3.00 | 1.0 | 15.00 | 300.00 | 45.00 | 13.50 | 313.50 | 6.50 |
| 5.00 | 1.5 | 14.50 | 190.00 | 72.50 | 21.75 | 311.75 | 8.25 |
| 7.00 | 2.0 | 14.00 | 280.00 | 100.80 | 30.24 | 310.24 | 9.76 |
| 10.00 | 2.2 | 13.80 | 276.00 | 132.48 | 39.74 | 315.74 | 4.26 |
| 12.00 | 2.4 | 13.60 | 272.00 | 163.20 | 48.96 | 320.96 | -0.96 |




*(a) Decrease in cement requirement* *(b) Reduction in cement percentage*

*Figure 4-9: Change in cement amount due to use of admixture*

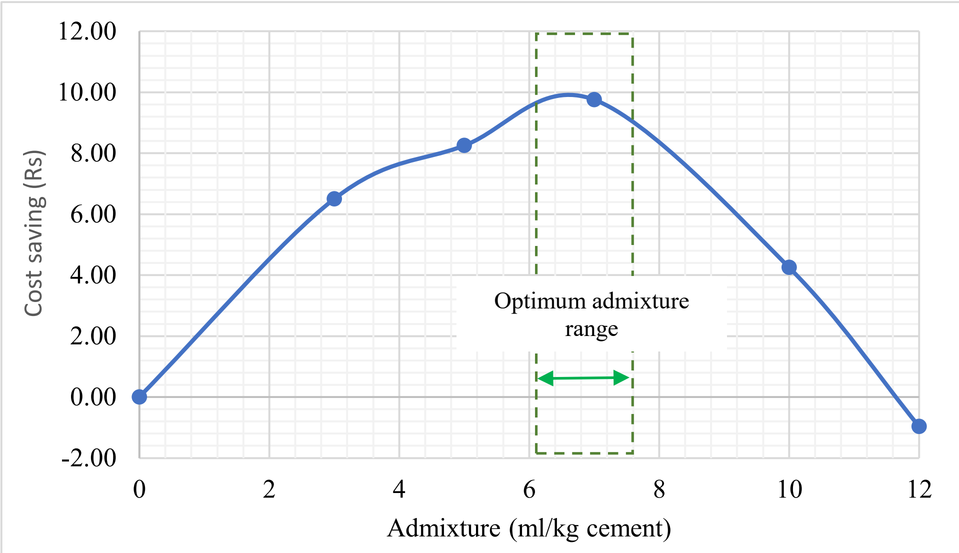



*Figure 4-10: Cost saving factor in the use of admixture for soil concrete*

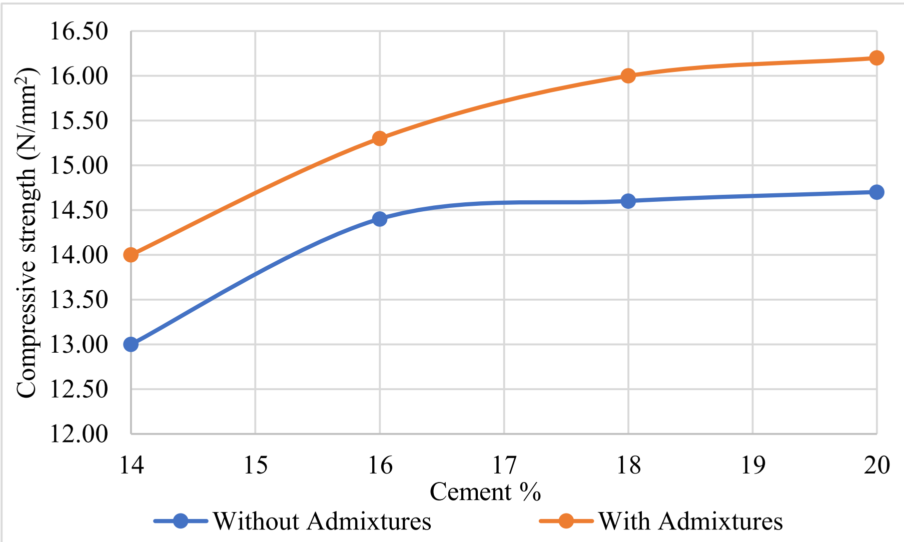



*Figure 4-11: Compressive strength variation with cement percentage*

### 4.5. Summary

The performance of soil concrete with chemical admixtures was investigated in this background. The chosen admixture was super plasticizers, and four different types of super plasticizers that are currently available used in cement concrete were considered.

The behaviour of the admixture with soil concrete was studied in terms of workability, strength and its economic impact. The workability and strength were determined using a flow table test and a compressive strength test respectively. According to the results, it could be concluded that the addition of admixtures could improve the workability of soil concrete as well as the compressive strength. This could lead to reduce the cement requirement. However, these findings showed that the chemical admixtures would enhance the soil concrete properties at different levels for different admixtures. The increase in strength shows a linear variation with the admixture amount. Though the use of admixture increases the compressive strength, its economical value is limited. The cost analysis results show that the optimum admixture usage is 6-7 ml/kg of cement. Therefore, the admixture dosage selection has to be done by considering its economical value. Though it is economically ineffective, it may show an environmental advantage in reducing the amount of cement. Accordingly, it is recommended to select the admixture type and dosage by considering all these relevant factors.

After completing the mix design process for the soil concrete floor base as stated in the two previous chapters, the next chapter focuses on selecting a floor coating to finish the soil flooring with proper durability and service characteristics.

# CHAPTER 5 : DEVELOPMENT OF TOP COATING

## 5.1. General

To meet the proper service requirement, the most adequate treatment for the protection of the top surface should be identified with respect to sustainability without compromising the naturalness of the soil concrete as far as possible while being cost effective. Ox blood, ghee, and vegetable oil are clear, low-cost natural sealers that were used to permanently seal the earth in ancient earthen floorings [7]. However, several other synthetic sealers, such as epoxy coatings, are available in today's construction industry as described in section 2.8. This chapter mainly focused on the selection of a suitable top coating and application methods.

When choosing the right coating, a number of critical criteria must be fulfilled, including the coating's ability to adhere to the substrate, water absorption, slip resistance, and wear resistance. Two synthetic coatings were selected from a variety of coatings and applied on the prepared soil floor samples to see if a smooth, durable surface finishes could be achieved.

Surface treatment cannot improve the strength of the material but improve its durability. The floor is the element which is the mostly used part in a building. Thus, it is widely exposed to static and dynamic pressures, chemical reactions, repeated washings, frequent drying, and wear and tear due to walking [188]. Therefore, the top surface of floor finishing materials must have numerous characteristics such as high resistance to water or chemical absorption, skid resistance, and wear resistance.

The bonding capacity of a coating with the soil concrete is one important characteristic to be considered in this context. Furthermore, the long-term water resistance could be determined by the difference in water absorption by capillarity on the coated and uncoated surfaces. Abrasion resistance is a good indicator of the evaluation of longevity under repetitive traffic. Therefore, the soil concrete floor was evaluated with the top coating for durability and service characteristics.

## 5.2. Preparation of floor samples with the selected soil concrete mix

A mix proportion was concluded with all the results obtained from the above sections. Then, the soil concrete was prepared according to the selected mix proportion and floor samples were cast to evaluate the floor performance. Steel moulds with the dimensions 600mm x 600mm x 75mm were used to cast the floor samples and the prepared soil concrete was poured into the moulds. Initially, a total of twelve (12) floor sample specimens were cast in three sets. Three test cubes (150mmx150mmx150mm) were also cast from each set of mixes to assess the compressive strength. Three samples from each mixture were oven dried for 24 hours at a steady temperature (105°C) to determine the moisture content. Eventually, the compressive strength test was done to confirm whether the selected soil concrete mix proportion was in the range of the required strength as a floor concrete (15 N/mm2). Figure 5-1 depicts the method of casting in the moulds as well as the prepared floor specimens. Specimens were removed from the moulds after 24 hours of casting, and all specimens were exposed to the same curing conditions before testing. After 28 days of curing, cubes were tested for compressive strength as stated in Section 3.3.2.3 and floor samples were tested for basic performance.

*Figure 5-1: The process of casting floor samples and prepared floor samples*

The compressive strength and moisture content values of soil concrete mix which were used to cast the floor samples are shown in Table 5-1. The compressive strength results and moisture content values confirm that the selected soil concrete mix proportion has fulfilled the strength requirements. This soil concrete mixing was done without using any admixture and with 18% cement. However, according to the results described in section 4.4, Figure 4-7 and Figure 4-8, addition of admixture could increase the strength or decrease the cement requirement.

*Table 5-1: Strength and moisture content values of selected soil concrete mix used to cast the floor*

| Mixture code | Avg. moisture % | Compressive Strength ($N/mm^2$) |
|---|---|---|
| **S1** | 18.2 | 15.3 |
| **S2** | 17.9 | 16.1 |
| **S3** | 18.8 | 15.8 |

First, the top surface appearance of the soil floor to be improved had to have a better architectural appearance and be smooth enough for user comfort. Therefore, the surface of the floor samples was smoothened after 28 days of casting.

### 5.3. Preparation of the top surface

After 28 days from casting, the surfaces were prepared in three different methods to smoothen the top surface. The three methods are,

Method 1 (T1) - Top surface ground using a grinder

Method 2 (T2) - Top surface ground using a grinder and sandpapered

Method 3 (T3) - Top surface ground using a grinder which was sand-papered after the application of the clay plaster in one or two layers and again sandpapered.

T3-1 – One layer of clay plaster

T3-2 – Two layers of clay plaster

T3-3 – Three layers of clay plaster

Figure 5-2 shows the process of surface preparation by grinding and sandpapering. The samples prepared according to T2 were used to further improve the surface in T3 with clay plaster.

*Figure 5-2: Process of surface preparation by grinding and sandpapering*

### 5.3.1. Surface preparation process in method 3 (T3)

The prepared floor samples according to the M2 above were further smoothened by applying a clay cement plaster. The clay in size < 0.425mm was prepared by sieving the soil by a 0.425mm sieve. Then the clay was mixed with cement in different cement to clay ratios. The clay and cement were mixed thoroughly in dry condition and then water was added little by a little while mixing thoroughly. Figure 5-3 shows the prepared clay cement mix and application process. Clay plaster was applied in one or two layers. The first layer was applied and kept for 24 hours in a moist condition to harden the surface. Then the surface was sandpapered to smoothen the setting. The No.400 sandpaper was used to smooth the surface, if one clay layer. If two layers, were used, the surface was smoothened by using No.180 water sandpaper after the first layer. This was followed by the application of the same clay cement plaster mix as the second layer. After 24 hours, the second layer was sandpapered by using No.400 sandpaper. The samples were stored in the laboratory for three months under ordinary indoor conditions, and the top surface appearance as a floor finishing material was monitored over time.

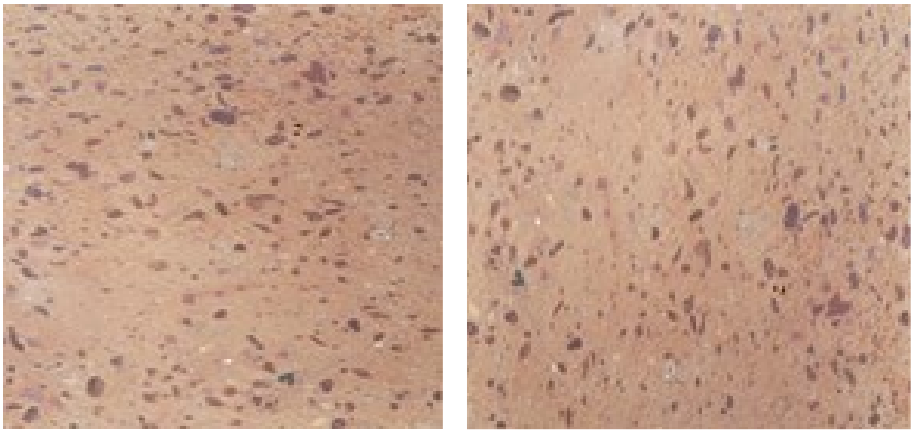
*Figure 5-3: prepared clay cement mix and application process*

The surface appearances of top surfaces prepared according to these three methods (T1, T2 & T3) gave three different appearances. This grinding process forms a better aesthetic appearance to the surface as the floor finishes. Figure 5-4 shows the surface appearance of the surface preparation.

*(a) Prepared in T1* *(b)Prepared in T2* *(c ) Prepared in T3*

*Figure 5-4: The surface appearance of soil floor after surface preparation*

Surface damage or any defects were not found during the surface smoothening process with the grinder.  The top surface of the floor samples prepared using T1 method was examined for appearance, surface defects, and degradation after three months. There were no visible changes in colour or texture, and there were no surface defects caused by shrinkage or damage to indoor environmental conditions. The surface appearance is visible in Figure 5-5.



*(a)  Initial appearance*                *(b) Appearance after three months*

*Figure 5-5: The surface appearance of soil floor samples after three months  prepared in T2 method*

However, the floor of a building normally undergoes a continuous wearing process due to cleaning with water and/or chemicals and wearing due to walking. Hence, further studies are required for the top surface finish to convert the soil concrete floor which has a more durable surface and best service characteristics.

Three surface preparation methods were adopted. The Method 1 (T1) Top surface was ground using a grinder, Method 2 (T2) Top surface was ground using a grinder and sandpapered and Method 3 (T3) Top surface was ground using a grinder and sandpapered after the application of the clay plaster. It is suggested that the approach of the top surface preparation method be chosen based on the desired level of smoothness and appearance of the floor. Next, the experimental process was done to introduce a top surface coating for the soil flooring material to meet the service and durability characteristics.

## 5.4. Materials and application of top coating

Two kinds of top coating materials were selected for initial testing to apply as a top surface coating on the floor surface. Phenol-formaldehyde resin (commercial product named as Novolac resin) and a floor sealer which is currently available in the market as floor coating were selected in this context.

### 5.4.1. Application process of the Novolac resin

The Novolac resin was available in the current market in solid form in golden coloured crystals as shown in Figure 6-1(a). According to the literature this Novolac resin is soluble in acetone. Therefore, industrial grade acetone was used to solve the Novolac resin (Figure 6-1(c)). The properties such as dimensional stability, tensile strength, and chemical resistance, of the Novolac resin could be improved after curing with hexamethylenetetramine (HMTA) [248] [249]. Therefore, the HMTA was used to cure the Novolac resin. The HMTA is available in the market as a white coloured powder as shown in Figure 6-1(b ).

*(a) Novolac Resin* *(b) HMTA* *(c ) Aciton*

*Figure 5-6: Materials used for top surface coating*

The application of Novolac resin on a soil floor surface is a novel process. Hence, there is no published data or any standard way to continue this research. Therefore, it was decided to commence the resin application process through a trial and error method in few steps. The resins could be applied in three different ways,

A1 - brush application, A2 - spray application and A3 - pouring and spreading over the surface by a scraper

Step 1

To commence the trial process, the resin was applied to raw samples (without doing any surface preparation) of the soil concrete floor. Three raw samples were taken in this background. The resin was solved in industrial grade acetone and HMTA was solved in water. The resin and HMTA ratio was kept constant as resin: HMTA in 1:6. Firstly, the resin was applied and allowed to air dry. Then HMTA was applied on the top of the resin layer. Initial preparation and application of resin and HMTA are shown in Figure 5-7. The application method A1 was used. Here it was found that once the resin layer air dried, the surface became water repellent. Due to this reason, it was decided to mix resin and HMTA and apply it on the surface.

*(a) Resin application* *(b) HMTA application*

*Figure 5-7: Application process of Resin and HMTA (Application method A1).*

Step 2

27 samples were cast according to the method defined in section 5-2. Then the top surface was prepared according to the method defined in section 5-3. To initiate the experiment series, the resin application was planned as shown in Figure 5-8.

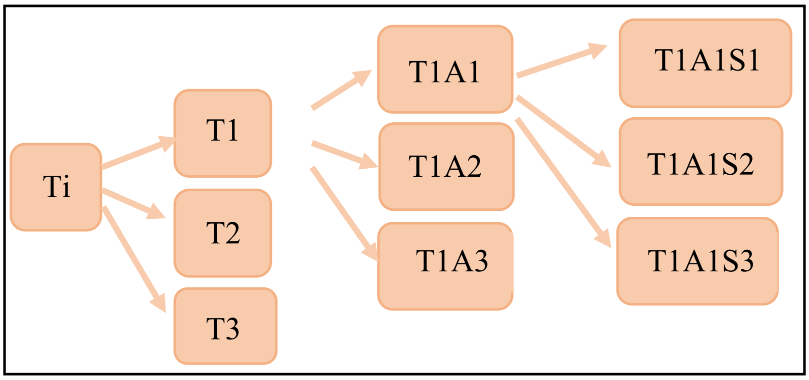



*Figure 5-8: Initial resin application plan*

Where Ti(i=1,2,3) – Top surface preparation methods

Aj(a=1,2,3) – Resin application methods

S k (k=1 to 9) – Floor samples

After applying the resin according to the above plan (Figure 5-8), samples were kept to air dry. Once the surface was fully dried, the samples were kept inside the oven to receive the proper temperature for curing. Initially, samples were cured for 2 hours in $180^0$C inside the oven. The samples were taken out from the oven after 2 hours and samples were allowed to achieve room temperature. Figure 5-9 shows the resin application process while Figure 5-10 shows the samples before heating. Figure 5-11 shows the samples inside the oven.

According to the resultant surface appearance, if the resin was over applied unevenly the final surface had bubbles giving an unsatisfied surface appearance and poor quality. The quality of the surface after resin application was not dependent on the surface preparation method and the application method. Further, the amount of resin applied on the surface significantly influences the surface appearance and the finished quality. The surface preparation method affected only the final appearance and the roughness. Figure 5-12 shows the final appearance of a few samples after the heating.

*( a) Brush Application (Method A1)* *(b) Apply using a scraper ( Method A3)*

*( c) Spray application (Method A2)*

*Figure 5-9: Resin application in three methods*

*Figure 5-10:Surface appearance after applying resin but before heating*

*Figure 5-11: Samples inside the oven*

*Figure 5-12: Surface appearance after heating due to over-application and overheating*

The surface did not have a pleasant appearance according to method T1. Also, the application method did not significantly influence the surface appearance but it was required to identify the correct temperature, resin: HMTA, and heating time. Therefore, experiments were continued to further improve the quality and appearance by identifying these factors correctly. Samples that are prepared according to the method T2 and T3 were selected because the surface prepared by these two methods gave a better appearance than the T1 samples. But samples without grinding are better with respect to the energy consumption since there is no energy requirement for grinding operations which are required for the other methods. The selection of the surface preparation method may depend on the required surface appearance, the location where the floor is going to lay and the expected surface smoothness.

Step 3

After preliminary observations, the temperature, curing time, resin: HMTA ratio are identified as the parameters to be considered to achieve the best surface coating. According to literature, the temperature and curing time depends on the resin: HMTA ratio and the temperature which is inversely proportionate to the HMTA amount. According to the scholarly data the curing temperature, Novolac: HMTA ration and time were decided [248] [249] [212] [220] [216] [221]. The surface coating was tested for all these parameters according to the arrangement shown in Figure 5-13.

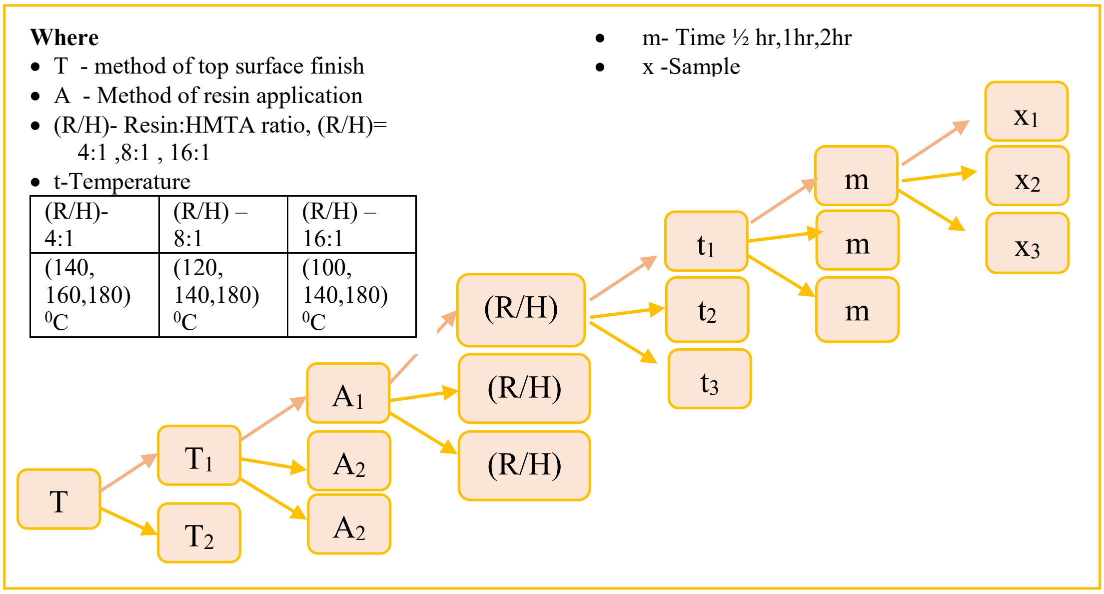



*Figure 5-13: Coating application plan*

According to the above plan, 486 samples were required in this context. Considering practical difficulties and limitations, 150 mm x 150 mm x 50 mm samples were prepared for this stage instead of 300 x 300 x 75 mm samples. In these samples, the only difference was the size of the sample. The soil concrete mix, the mixing method, casting and surface preparation method were the same as described in the above sections. After the process of coating, the surface appearance of all the samples gave the same appearance with minor differences. These differences were only due to the method of top surface preparation. The appearance of a few samples are shown below in Figure 5-14.

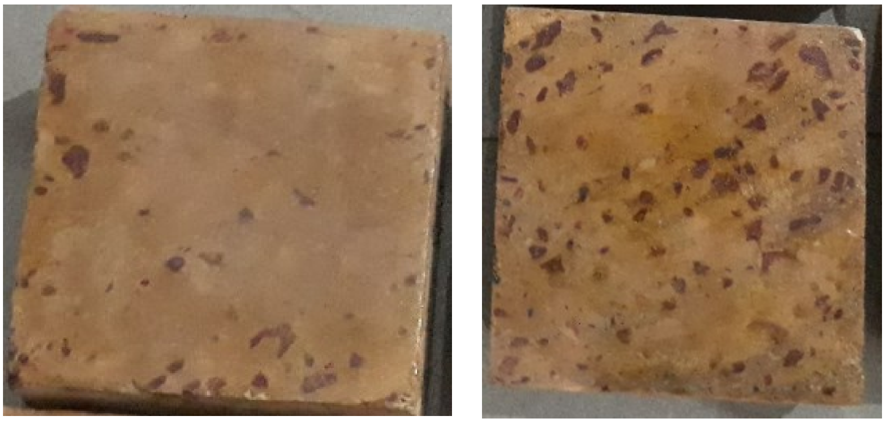


*Figure 5-14: The surface appearance of samples after the coating process*

Out of all these samples few observations were made,

1. Resin: HMTA ratio did not significantly influence, therefore, HMTA was used in lesser amounts in the ratio of 1:8

2. The over-application of resin had severely affected the appearance, therefore, the resin had to be applied as a very thin layer.

3. In laboratory conditions, the spray application (A2) and brush application method (A1) for small samples were not effective, therefore, method A3 was selected. But in mass application the spray method (A2) and Brush application (A1) were applicable.

4. In real practice, the temperature application for curing is not practical inside the oven since the proposed product was an in-situ flooring system. Therefore, other method was tried.

With the above conclusions made, experiments were continued for further improvement of the surface coating.

5.4.1.1. Improvement of the heat treatment method

the planned product is an in situ flooring system, the temperature application for curing is not possible inside the oven. As a result, an attempt to solve the issue using some other heat application method was used in this situation.150 mm x 150 mm x 50 mm samples were used again. The resin was applied to the prepared surface. LP gas flame was used to apply heat on the floor surface. Initially, heat was applied on the surface using an LP gas flame for a different time period in different strengths. It was observed that the strength of the gas flame significantly influenced the coating. The resin was burnt and it gave a dark coloured surface due to overheating. After a series of heating processes with different time and flame strength, it was decided to heat the 150 x 150 mm floor area for two (2) minutes to achieve better results. Therefore, a single layer of resin was applied on the sample surface and heat was applied over the surface for two (2) minutes. Then the surface was allowed to come back to the room temperature. The surface was then smoothened by grain size 1000 (No 1000) water sandpaper. Consequently, the surface gave a better appearance. But the second coating layer was made for further improvement.  The heat was applied to the second layer also as the first layer. After the surface came back to room temperature, it was cleaned by using water with a tile cleaner chemical. The heating process was shown in Figure 5-15 and The appearance of the final product is shown in Figure 5-16.

*Figure 5-15: The heat application process*

*Figure 5-16: Appearance of the final product*

In the series of experiments done by trial and error method, it was concluded that the Novolac resin with HMTA could be used as a coating material on the soil concrete floor base with several recommendations

1. The resin layer should be as thin as possible.
2. Heat application to be done carefully to avoid overheat
3. The method of surface preparation (T1, T2, and T3) could be selected and it depended on the required surface appearance, and the expected roughness.
4. Any method of application (A1, A2, and A3) could be selected based on equipment availability.

### 5.5. Top surface coating on the soil floor with the floor sealer

Cut cement flooring is a popular trend for hotels, resorts and personal residencies due to the natural look for modern building walls and floors with a durable and attractive finish. The laying method of this cut cement floor is similar to the in-situ terrazzo flooring.

There are several types of floor sealers to apply in this type of flooring with a proper floor finish for terrazzo and cut cement floors. Therefore, the floor sealer which is readily available in the current market was applied on the soil concrete base. The selected floor sealer was applied on the prepared floor samples according to the instruction given by the manufacturer. The surface appearance of soil floor after applying the floor sealer is shown in Figure 5-17.

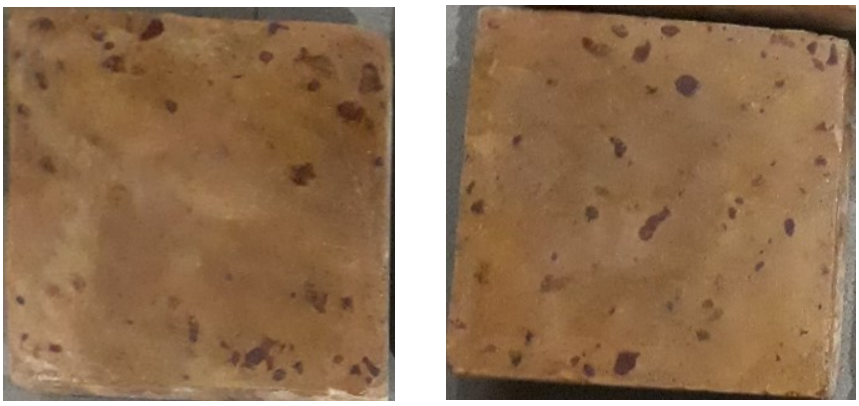


*Figure 5-17: Appearance of soil floor, (top surface finished with a floor sealer)*

Once the soil floor system has been established, it is necessary to examine the reliability and service characteristics of the proposed new flooring system. As a result, the following steps will focus on the experiments that were conducted to determine the reliability and service characteristics in greater detail.

## 5.6. Durability and service characteristics

Bond performance, water absorption, skid resistance, abrasion resistance and stain resistance were evaluated in this section as indication of serviceability and durability characteristics of proposed soil floor.

### 5.6.1. Bond performance

Adherence between the soil concrete floor base and the top surface wash coat was determined by pull-off tests according to the ASTM D4541[250]. Five soil concrete samples prepared from each type top coatings were tested for bond performance. Figure 5-18 shows the schematic representation of the pull-off principle.

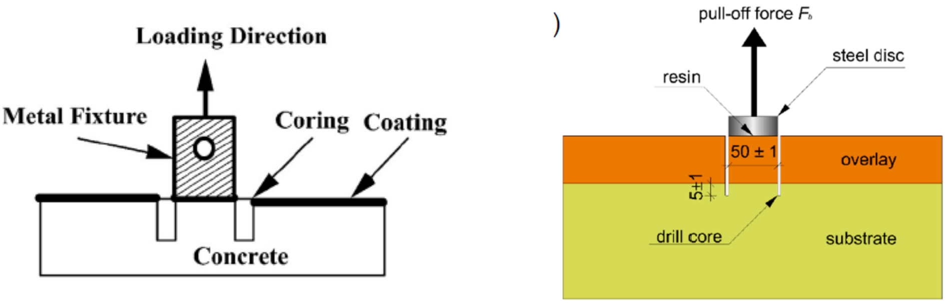



*Figure 5-18: The schematic representation of the pull-off principle[199]*

Metallic plates of 50 mm x 50 mm with a thickness of 5 mm were used as the pull off head plate. First, the test area was cut into fit the pull-head plates with a 5 mm deep cut in the floor sample (substrate) in a square shape in order to guarantee that the pulling off occurs only under the disc. The same type of plate was used for all samples, to avoid that the affected type of plate on the results by plate geometry variation. The sample preparation was shown in Figure 5-19. A metal plate was glued to the resin surface by using a rapid setting epoxy. The procedures of the application of the bonding agent on the metallic plate and surface of the floor were done in accordance with the manufacturer's specifications.

*Figure 5-19:Prepartion of floor samples for Pull-off test*

As seen in Figure 5-20, the loading mechanism was then set up to add a pull of load to the metallic pad. The load was gradually raised, and the bonding strength was measured by pulling the substrate's metal layer. The failure load was assessed using the dial gauge mounted on the device. The pulling off resistance, or the highest strain that could be applied to the coating, was measured as the ratio between this force and the disk transverse area.


*Figure 5-20:Pull-off  test procedure*

The observed average pull of load on the plate was 120Kg.

The area of fracture surface $= 50 \text{ mm} \times 50 \text{ mm}$

$= 2500 \text{ mm}^2$

Pull off strength was calculated using Equation 5-1

$$\boxed{S = FT / A_f}$$ *Equation 5-1*

where

S - Pull off strength, FT - pull off force, $A_f$ - Area of the fracture surface

$$S = 120 \text{ kg}/2500\text{mm}^2$$
$$= 0.48 \text{ N/mm}^2$$

The average maximum load that was able to tolerate the system was observed as 0.48 N/mm$^2$. The failure surface and failure pattern are shown in Figure 5-21.

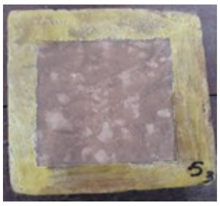
*Figure 5-21:Observed failure pattern*

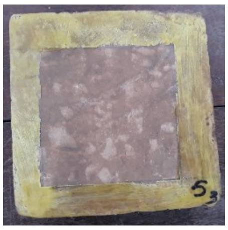
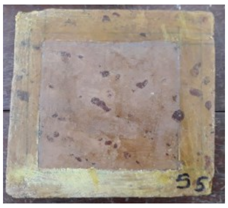
Pull out failure occurred through the soil concrete base, the fracture was not through an interface between the coating layer and soil concrete base. According to the observed failure pattern, it was concluded that the resin layer was hardly bond to the base concrete.

### 5.6.2. Water absorption and sorptivity

The sorptivity test was done in accordance with ASTM C 1585 – 04 [251]. Twenty-one soil floor samples were prepared for the sorptivity test. A typical sample was in the size of 150 x 150 x 50 mm, which was used although results did not depend on sample size. The top surface was finished in seven different ways as shown in Table 5-2 and three samples from each way.

*Table 5-2: Samples designation for sorptivity test*

| Sample Name | Description | Surface appearance |
|---|---|---|
| $S_1$ | Soil concrete base only, Top layer prepared according to the Method M2, No top coating applied on the top surface |  |
| $S_2$ | Soil concrete base prepared according to the Method M2, two coats of resin applied on the top surface |  |
| S3 | Soil concrete base prepared according to the Method M3-1, no top coating applied on the top surface |  |
| S4 | Soil concrete base prepared according to the Method M3-2, no top coating applied on the top surface |  |

| | | |
|---|---|---|
| S5 | Soil concrete base prepared according to the Method M3-1, two coats of resin applied on the top surface |  |
| S6 | Soil concrete base prepared according to the Method M3-2, two coats of resin applied on the top surface |  |
| S7 | Soil concrete base prepared according to the Method M3-2, two coats of floor sealer applied on the top surface |  |

Test specimens were put in a desiccator with a temperature of 50°C for 3 days with a constant relative humidity in the desiccator. Every specimen was put inside a sealable container after three days. Each specimen was placed in its own container, allowing free ventilation around the specimen and preventing contact with the container walls. The containers were held at 23 °C for at least 15 days before being put to the test. Before sealing the side surfaces, the specimens were removed from the storage container and their original weight was recorded to the nearest 0.1g. In addition, the dimensions of the specimen at the surface to be exposed to water were measured to the nearest 0.1 mm. The side surface of each specimen was sealed with paraffin wax. Figure 5-22 shows the schematic diagram of the arrangement of the test specimen according to the ASTM C 1585-04 [251].

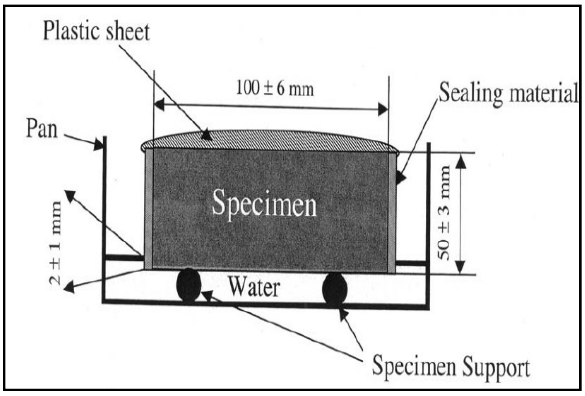



*Figure 5-22: Schematic diagram of the procedure (ASTM C 1585 – 04) [251]*

The rate of water absorption was calculated as a function of time. The absorption test was carried out at 23°C with tap water. As the initial mass for water absorption measurements, the weight of the sealed specimen was determined to the nearest 0.1 g. As a support unit, 5mm diameter plastic rods were put at the bottom of the pan, and the pan was filled with tap water to a depth of 3 to 5 mm above the tops of the rods. When the measurements were over, the water level was held between 3 to 5 mm above the tops of the poles. The specimen was then secured to the support unit. Figure 5-23 depicts the planning and organization of the specimens.

*Figure 5-23: Preparation and the arrangement of the specimens*

The time of initial contact with water was noted. The weight was taken at the time intervals after the first contact with water and the first reading was noted at 5 min.

Subsequent measurements were recorded after 10 min, 30 min, and 60 min, 120 min,180 min, and finally after 24hrs.

For each weight measurement, the test specimen was removed from the pan, stop the timing device and surface water was mopped off with a cotton cloth. After removing excess water, the specimen was turned upside down to prevent the wet surface to come in contact with the balance pan. The weight of the specimen was noted to the nearest 0.1 g within 30 s of removal from the pan. Then, immediately the specimen was placed on the support device and the timing device was restarted. The same procedure was followed for all the specimens.

The results were analyzed under the topic of water absorption, water absorption rate, and sorptivity.

**Water absorption (*i*)**

The absorption, *i*, is defined in ASTM C1585-4 [180] as the change in mass divided by the product of the cross-sectional area of the test specimen and the density of water. In this test, the temperature dependence of the density of water was neglected and a value of 0.001 g/mm$^3$ was used. The units of *i* are mm. Water absorption was calculated using Equation 5-2 and the rate of water absorption was calculated using Equation 5-3. The resultant water absorption is shown in Figure 5-24 and Figure 5-25 shows the rate of water absorption.

$$\boxed{\text{Water absorption (i)} = m_t / (a \times d)} \quad \textit{Equation 5-2}$$

$$\boxed{\text{Rate of water absorption} = m_t\ (a \times t)} \quad \textit{Equation 5-3}$$

where:

i = the absorption    t = Time

a = the exposed area of the specimen in mm$^2$

d = density of water

$m_t$ = the increase in specimen mass in grams, at the time t

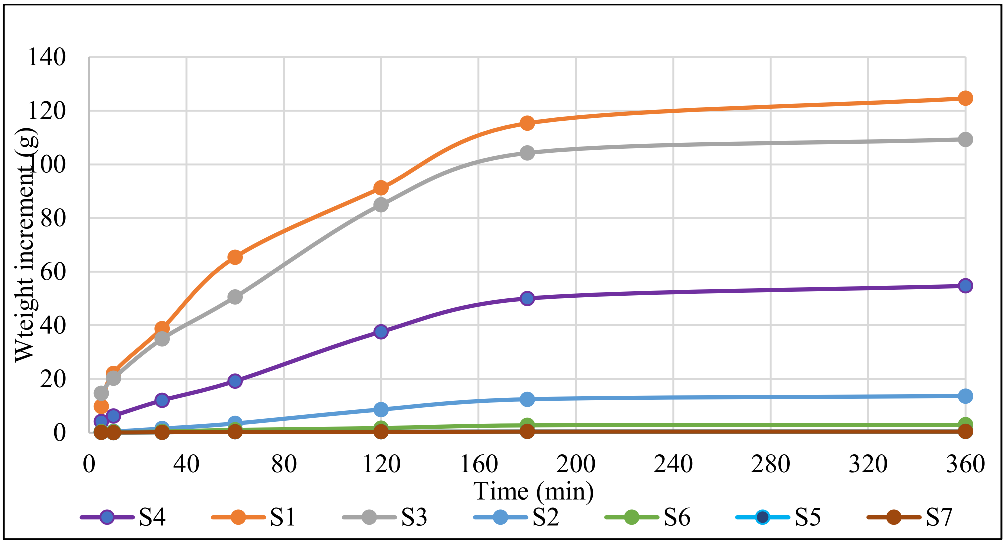



*Figure 5-24: Water absorption*

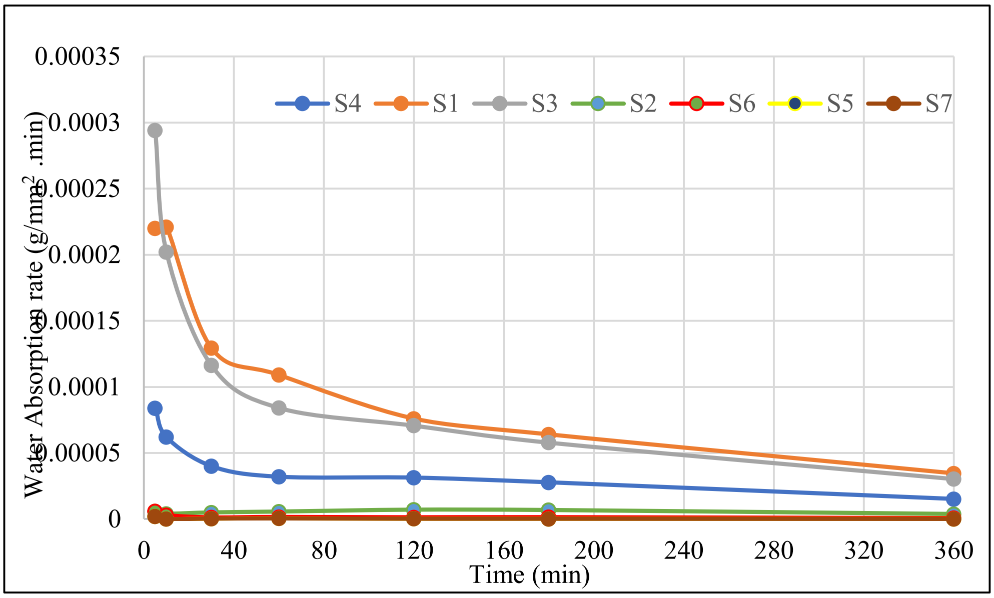


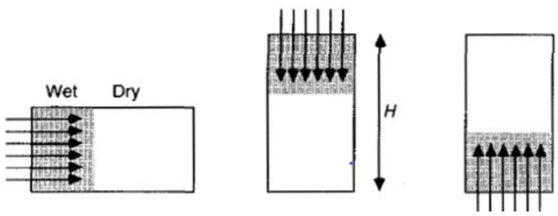

*Figure 5-25: Rate of water absorption*

Results show that water absorption was highly influenced by the top surface finishing method. The water absorption and rate of water absorption was negligible for the samples S6, S5 and S7 which were surface prepared with a clay plaster and top coats. However, water absorption of sample S2 which did not have any clay plaster but a resin top coat was the next lowest value closer to that of S6 and S5 values. This states that the top coat effectively provides the ability to water-repellent property to the floor.

The water absorption difference between S5, S6 & S7 and that of S2 was lesser than the water absorption difference between S4 and that of S2 with a considerable amount. This observation said that the water absorption property could be improved even without the clay layer effectively but would not do without the resin. Water absorption of S4 is lesser than water absorption of S3 giving a considerable difference. But water absorption of S3and S1 shows closer values. Hence, it could be noted that the two layers of the clay plaster were effective than the single clay layer. The water absorptions of three samples without resin layers (S4< S3< S1) were very much higher than that of samples with a wash coat.

**Sorptivity (S)**

The slope of the line that is the best match to (i) was plotted against the square root of time ($t^{1/2}$) which is known as the initial rate of water absorption (sorptivity) (mm/$s^{1/2}$). Using least squares, linear regression analysis of the plot of i versus time $(t)^{1/2}$, obtain this slope using all of the points from 1 minute to 6 hours for the regression analysis. Sorptivity (S) was determined by assuming a linear variation between the absorption (i) and the square root of time (t), as expressed in Equation 5-4 for one dimensional water absorption case and many building materials, water absorption rates measured in the three configurations (Figure 5-26) ([252]). Figure 5-27 shows the plot of I with $(t)^{1/2}$ and calculated sorptivity is shown in Table 5-3 for floor samples.




*(a) (b) (c)*

*(a) the horizontal case, in which the water absorption rate is independent of gravitational effects;*

*(b) the infiltration case, total flow being the sum of capillary-driven and gravity-driven flows;*

*(c) the capillary rise case, in which the effects of capillarity and gravity are opposed*

*Figure 5-26: One-dimensional water absorption into a sample of porous material from a free-water reservoir*

$$i = S\,(t)^{1/2}$$ *Equation 5-4*

Where

i -The cumulative water absorption per unit area of the inflow surface (mm)

S - Soptivity

t - Time (s)

The results show that the sorptivity which is one of the most important properties, effectively contribute to the durability of the floor which could be improved by selected synthetic top coatings.

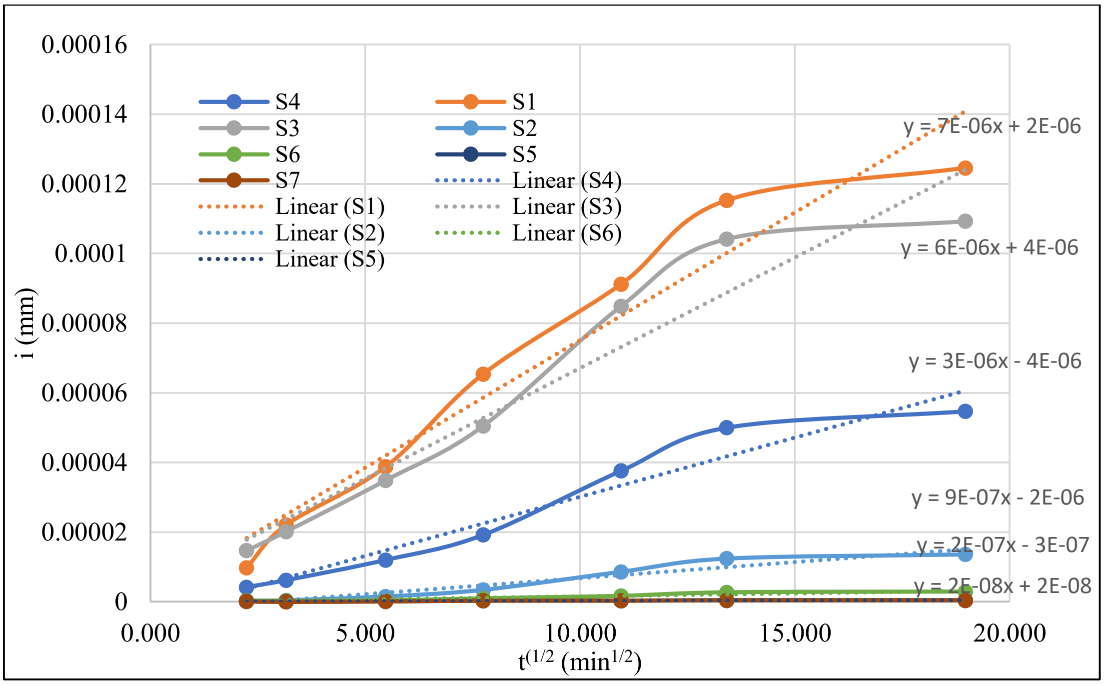



*Figure 5-27: Plot of i with $(t)^{1/2}$*

*Table 5-3: Soptivity for the floor samples*

| Sample no | Sample with | | | | Sorptivity (s) $10^{-6}$x mm/$s^{1/2}$ |
|---|---|---|---|---|---|
| | Clay: cement plaster | | Resin | Sealer | |
| | 1st layer | 2nd layer | Two layers | Two coat | |
| S1 | | | | | 7 |
| S3 | | | | | 6 |
| S4 | | | | | 3 |
| S2 | | | | | 0.9 |
| S5 | | | | | 0.2 |
| S6 | | | | | 0.2 |
| S7 | | | | | 0.2 |

### 5.6.3. Slip resistance

Slip resistance was done according to the ASTM E 303-93 [253], standard test method for measuring surface friction properties using the British Pendulum Tester. The British Pendulum Tester is a dynamic pendulum impact type tester used to measure the energy loss when a rubber slider edge was driven over a test surface. The tester consists of a pendulum with a slider and a 1.5Kg slider mount. A slider is capable of adjusting vertically to make a slider contact path 125mm and the slider consists of a 76mm rubber strip was used in this context. Before starting the test, the instrument was levelled using levelling screws and the apparatus was tested for zero adjustments. Samples were prepared as S2, S5, S6, S7 which were with the best water absorption quality three samples from each were tested. First, the pendulum slider was fixed to freely move in contact with the test surface. Then the floor sample was clean to free from loose particles and fixed rigidly to the apparatus so that it did move by the force of the pendulum. The arrangement of the apparatus is shown in Figure 5-28.

The average BPN for wet and dry was tabulated in Table 5-4. The slipperiness classification was based on the wet BPN according to the ASTM E 303-93 is shown in Figure 5-29

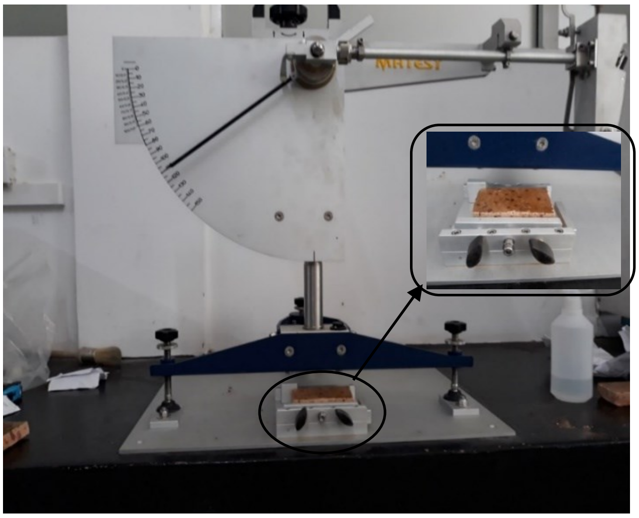


*Figure 5-28: Slip resistance test – British Pendulum Tester*

| Pendulum Test Value (PTV) | *Potential for slip |
|---|---|
| 25 and below | High |
| 26 to 35 | Moderate |
| 36 to 65 | Low |
| 66 and above | Extremely low |

*Figure 5-29: Pendulum Test Values and potential to slip according to ASTM E 3030-93 [254]*

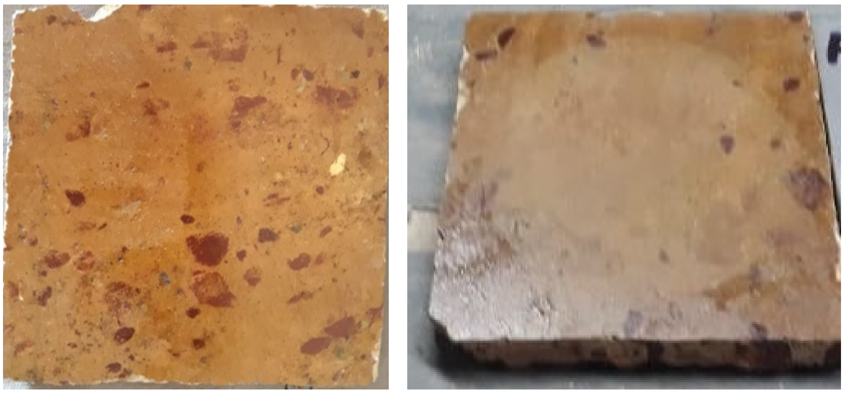
*Table 5-4: British Pendulum test values (BPV)*

| **The value was measured as British Pendulum Number** | **BPN** | |
|---|---|---|
| | DRY | WET |
| S2 | 50 | 20 |
| S5 | 45 | 18 |
| S6 | 48 | 19 |
| S7 | 50 | 23 |

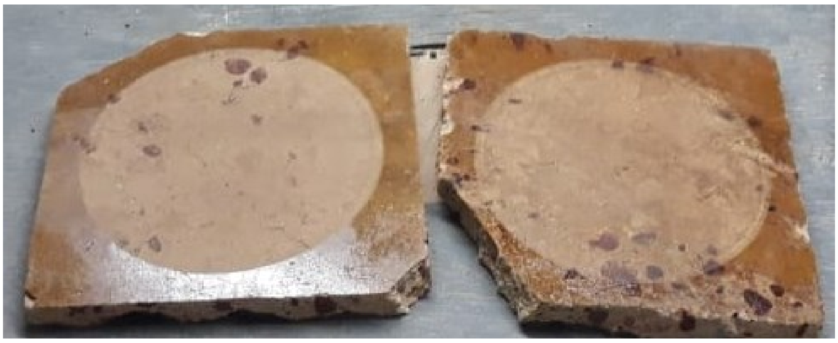
### 5.6.4. Ware / Abrasion resistance

The abrasion resistance was measured at the Lanka tile (pvt) Ltd factory complex at Meepe in accordance with ISO 10545 – 7. The prepared floor samples were subjected to abrasion load inside the test apparatus. After abrasion, the specimen was rinsed under running water and was dried in an oven at 110 (-,+5) $^{0}$C. The specimen was subjected to visual assessment under illuminance of 300 lx. The specimen was viewed from a distance of 2 m and a height of 1.65 m. The number of revolutions at which any change in the area that has been subjected to abrasion was noted. The testing procedure and the sample after testing are shown Figure 5-30 and Figure 5-31. The samples could be classified according to the failure visible at revolutions. For the glazed ceramic tiles, the classification system is shown in Figure 5-32 [255]. According to the observed results, soil concrete floor could be classified in class 1. But the testing procedure describes testing for glass ceramic tiles.

*Figure 5-30: Abrasion test procedure in the laboratory at Meepe Lanka Tile factory*



*After 150 revolutions (b) after 300 revolutions*



*(c ) After 600 revolutions*

*Figure 5-31: Surface appearance after abrasion in abrasion resistance testing machine ( samples with resin)*

**Table 1 — Classification of glazed ceramic tiles**

| Abrasion stage; Failure visible at revolutions | Class |
|---|---|
| 100 | 0 |
| 150 | 1 |
| 600 | 2 |
| 750, 1 500 | 3 |
| 2 100, 6 000, 12 000 | 4 |
| >12 000 1) | 5 |

1) Must pass the test specified in ISO 10545-14 for resistance to stains.

*Figure 5-32: Tile classification system according to the ISO 10545 – 7[256]*

### 5.6.5. Stain resistance

This test is performed according to the method described in BS EN ISO 10545-14: 2015, Determination of resistance to stains [256], which consists of applying a few drops of the following reactive agents on the surface of five test pieces. Determination of the resistance to stains is achieved by maintaining the test solutions and materials in contact with the tiles for a suitable length of time (24 hrs). The symmetric diagram of the stain resistance test was shown in Figure 5-33

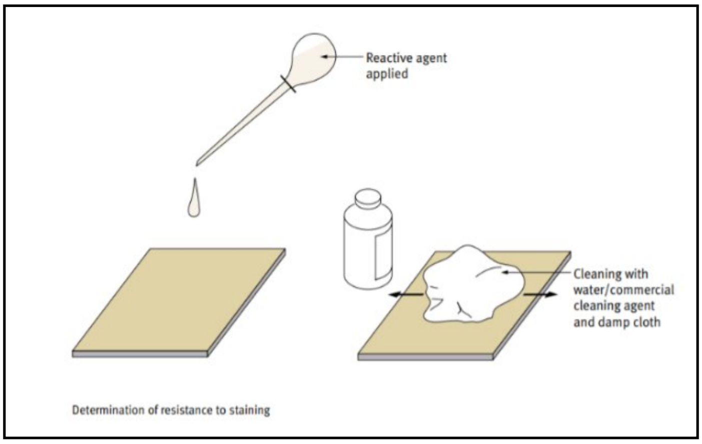



*Figure 5-33: Symmetric diagram of stain resistance test [257]*

In this experiment series, stain resistance was done in the same laboratory at Lanka wall tile factory.  Drops of Potassium permanganate and Methil blue was put on the surface (Figure 5-34). Five samples were tested in this context. After 24 hours they were washed out with pure water and the surface was observed. But no discolouration was observed on the original floor, but after abortion, a colour patch could be observed (Figure 5-35 & Figure 5-36).

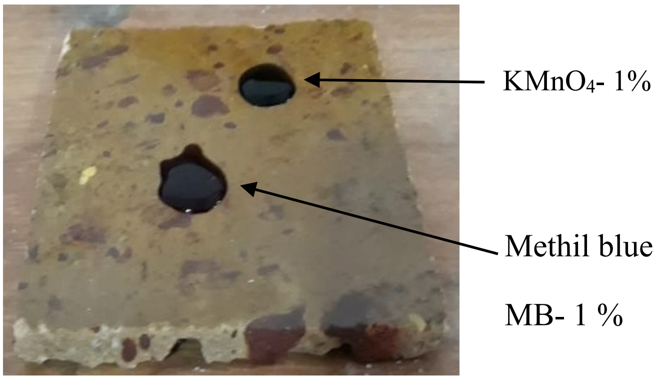
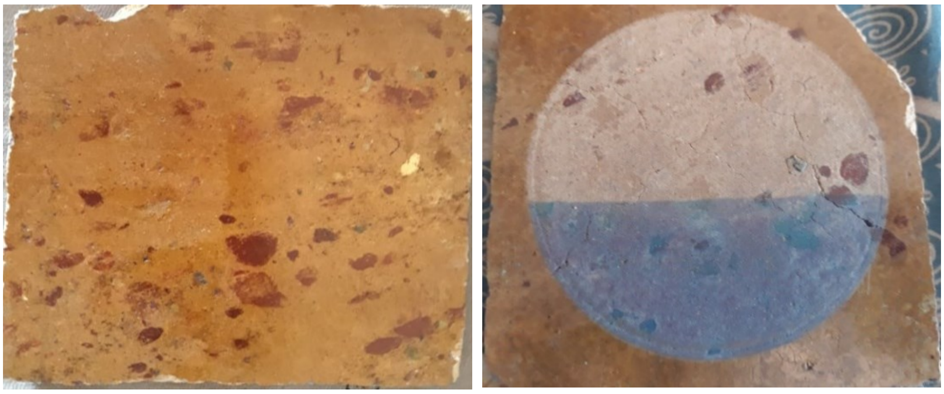



*Figure 5-34:Application of the test solution on the test sample*



*(a)  non abrated surface*   *(b) surface after 600 revolutions on abrasion resistance test machine*

*Figure 5-35: Surface appearance after 24 hr samples with resin*

*(a)  Before abrasion*   *(b) after 600 revolution*   *(c ) After 1000 revolutions*

*Figure 5-36: Abrasion resistance test results floor sample with the floor sealer*

## 5.7. Summary

The development of coatings for soil flooring was described in this chapter. Firstly, approaches for improving the appearance and smoothness of the surface were examined. Three surface preparation methods were adopted as Method 1 (T1) - Top surface ground using a grinder, Method 2 (T2) - Top surface was ground using a grinder and was sand-papered and Method 3 (T3) -Top surface ground using a grinder and sand-papered then applied clay plaster. It was suggested that the approach of the top surface preparation method be chosen based on the desired level of smoothness and appearance of the floor. Next, the experimental process was done to introduce a top surface coating for the soil flooring material to meet the service and durability characteristics. Then, the selection and application of the top coating material were discussed. Consequently, the Novolac resin cured with HMTA and floor sealer were selected as a suitable top surface coating. The application method and heat treatment process of the Novolac resin application were discussed in this chapter too. Finally, the soil concrete flooring system was concluded in three layers, namely the soil concrete floor base, topped with a clay plaster and a top coat with a synthetic resin as shown in Figure 5-37.

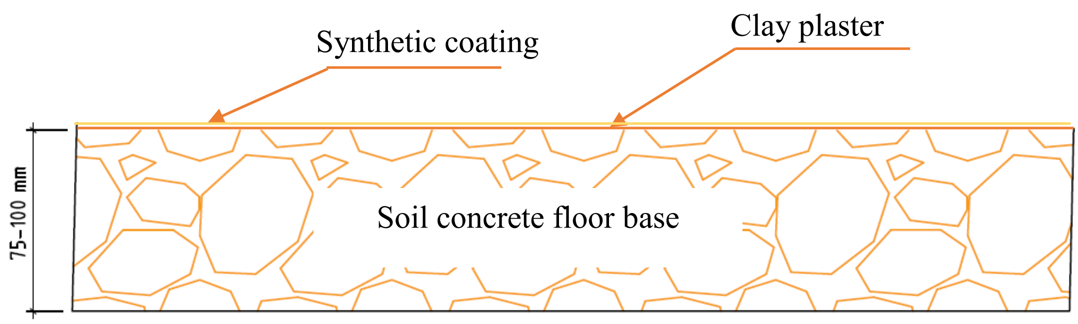



*Figure 5-37 : Symmetric diagram of soil concrete flooring system*

Then the bond performance of top surface coating with the floor base, the water absorption and sorptivity, the slip resistance, ware / abrasion resistance, and stain resistance was examined according to the relevant standards. The abrasion resistance test in the resin application failed despite the fact that all other service and durability requirements (bond strength, sorptivity, slip resistance, stain resistance before abrasion) were met. In addition, heat treatment of the resin on a mass scale was a challenge in practice. As a result, the floor sealer was selected as a suitable top surface coating for soil flooring. The real scale behaviour of proposed flooring and cost benefit analysis was also carried out. The next chapter will discuss the work done to analyse the real scale behaviour of proposed flooring and the cost benefit analysis and the work carried out to compare the soil concrete floor with other selected existing flooring materials.

# CHAPTER 6 : REAL SCALE BEHAVIOR OF PROPOSED FLOORING AND COST BENEFIT ANALYSIS

## 6.1. Construction of soil concrete floor in large scale

At the end of the series of the laboratory experiment, soil concrete mix proportion, method of construction, top surface finishing material and application method were concluded. As the final part of the research experiments, this chapter is allocated to describe the work carried out to observe the real scale behaviour and cost benefit analysis. First, soil concrete floor on a large scale was cast. Then, soil concrete floor was compared with other selected existing floorings with respect to the thermal performance. The selected floorings were the ceramic tile and cement rendered floor for comparison purposes.

For the thermal performance evaluation, soil concrete floor was laid in large size in three steps and closer to the soil floor, selected floors with selected materials were also cast in equal environment conditions.

Step 1: Floor base casting

For this purpose, the residence under construction located at Homagama was selected. The soil was extracted from the same location by digging a pit. The extracted soil was sieve to remove the larger particles larger than 25 mm. Extracted soil heap and sieving process are shown in Figure 6-1. Then soil was subjected to sieve analysis to understand the gravel, sand, and fine particles in the extracted soil. The results said that the extracted soil consists of 35% of gravel, 55% of sand, and 10 % of fine particles on average. Therefore, this soil was able to use as it is without any further modifications. Selected floor area for this casting was 42ft$^2$ (6 ft x 7 ft).

The floor area was compacted and levelled firmly. The soil and cement were mixed thoroughly in dry conditions. Then they were mixed with water and poured onto the prepared floor. It was compacted manually and levelled. Two unskilled labour worked under the supervision and the work was completed within three hours. The construction process is shown in Figure 6-2 and Figure 6-3 shows the cast floor in green state.

*Figure 6-1: Extracted soil for floor construction and the soil sieving process to remove larger particles*

*Figure 6-2:Floor construction work*

*Figure 6-3: Soil concrete floor in the green state*

**Step 2- Floor top surface preparation**

After two weeks from the floor base construction, the floor was cut using a terrazzo cutting machine. The machine was taken to the site on a hired basis and the machine was operated by unskilled labour under the supervision. First, the floor was cut by using a medium grain size cutting stone followed by a fine grain cutting stone. Two hour time duration was taken for this process. The process and the finished surface are shown in Figure 6-4. Then prepared clay slurry was applied on the surface as shown in Figure 6-5. Finally, the surface was further smoothened by using grain size 1000 water sandpaper. Now the soil concrete floor was ready to apply the wash coat.

*Figure 6-4: Floor surface cutting process with terrazzo machine*

*Figure 6-5: Clay slurry application*

**Step 3- Wash coat application**

After applying clay plaster, the floor sealer was selected as a wash coat and applied on the soil floor surface. The appearance of the final floor is shown in Figure 6-6.

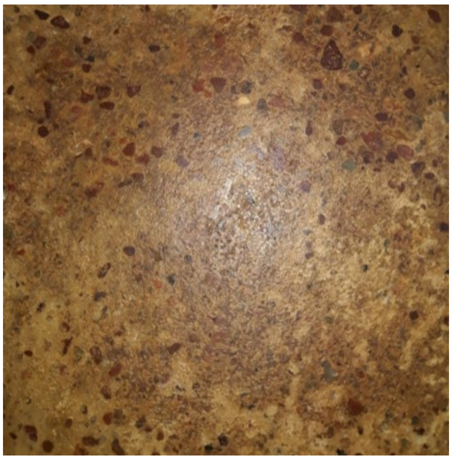
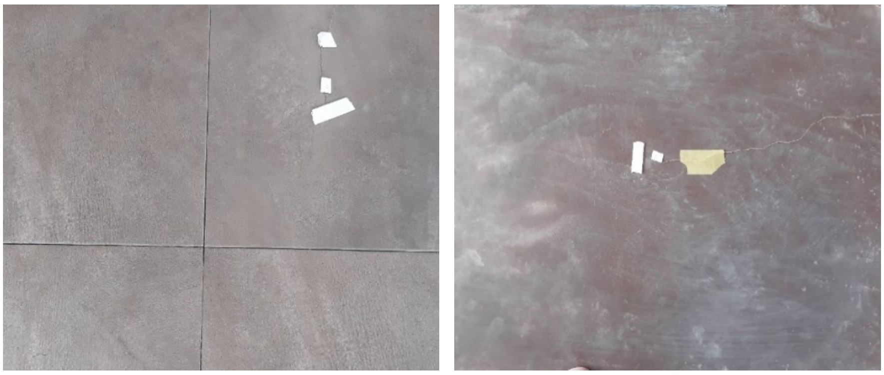


*Figure 6-6: Appearance of final floor*

## 6.2. Comparison of thermal performance of soil concrete floor with other existing floorings

The thermal performance of the soil-based floor was determined and compared with two other commonly available flooring materials. The selected floor materials were cement rendering, ceramic tile in addition to soil floor. The colour of ceramic tiles was selected to match with the soil concrete and the cement rendering also was done by adding colour pigment to the cement to match the colour to avoid the colour effect on the surface temperature.  Areas of 6ft x 6ft was laid with selected floorings for each other at the place where indoor environment conditions are the same. Then the temperature variation was measured on the floor surface continuously for two weeks period using a data logger as shown in Figure 6-7. The temperature on the floor surface and indoor temperatures were also measured. Then the temperature variation on the surface was compared. The average temperature throughout the day (24 hrs) was plotted against time as shown in Figure 6-8.

*(a)  Data logger* *(b) Soil concrete floor*



*(c ) Ceramic tile floor* *(d) Cement rendered floor*

*Figure 6-7: Temperature measurements*

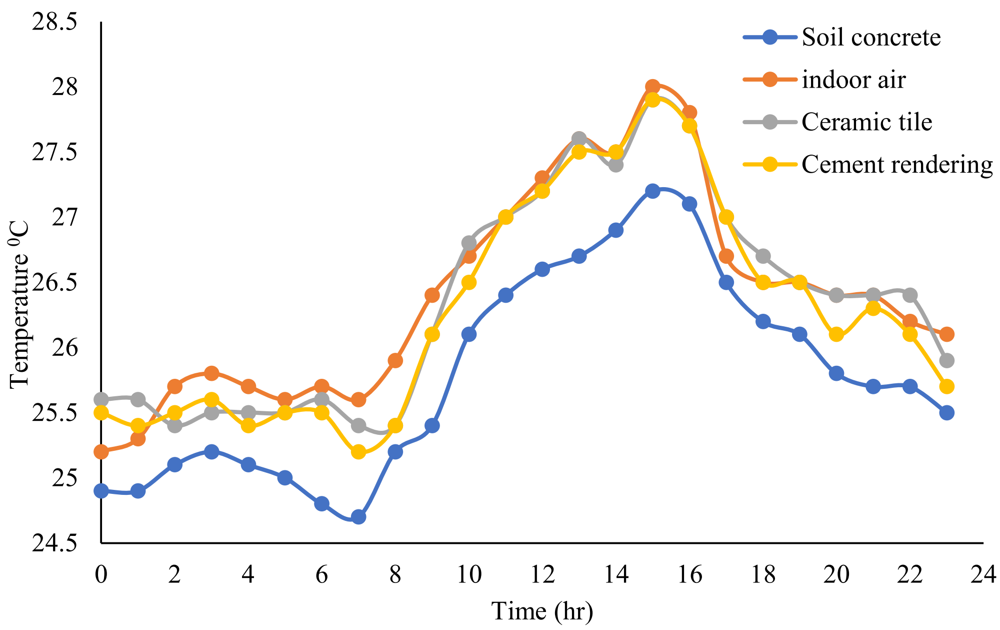



*Figure 6-8: Comparison of surface temperature variation on the floor surfaces*

According to the temperature variation pattern, the soil concrete floor showed lesser top surface temperature in a significant level compared with other floorings and also indoor air temperature. The maximum indoor air temperature was observed at 15-16 hr and it was 28$^0$C and at that time the temperatures were 27$^0$C, 27.8$^0$C, 27.8$^0$C on soil floor, cement rendered floor and ceramic tile floor respectively. The results showed that the temperature on the soil floor was 1$^0$C lesser than that of other floor surfaces as well as indoor air temperature. Further, it could be seen that throughout the day the soil floor surface temperature showed a lower value than other surface and indoor air temperatures as well in a significant amount. Therefore, it can be concluded the innovative soil floor can be used to keep indoor thermal comfortability and save energy use for air condition too.

### 6.3. Construction of real scale floor

Once the soil flooring was finalized after the laboratory experiment series, the real scale floor was cast. For this, the guest house floor was finished with the soil floor which was innovated in this research. The selected guest house is located at Chilaw and it is a small gest house constructed for visitors. The guest house floor plan is shown below Figure 6-9 and consists of 600.00 ft$^2$ total floor area. The floor consists of different sizes of floor areas. This helped to identify whether there may be cracks or not and if crack initiated to identify the crack pattern and propagation style.

Drying shrinkage causes slabs to contras, or shorten. If slabs are free to contras, tensile stresses and cracking do not occur. Unless jointed properly, drying shrinkage combined with restraints classically produces random slab cracks, dissatisfied owners and costly repairs.

Curling is caused by differential shrinkage associated with different moisture contents in the top and bottom portions of interior floors. Because drying or moisture loss is primarily from the top of the slab, a moisture gradient is created between the top and bottom of the slab, especially when the subbase is moist. The reduced moisture content in the top portion causes the top of the slab to shrink more than the bottom. The level of curling is directly related to the moisture gradient and the shrinkage potential of the concrete. If properly jointed, slab shortening should occur in the joints and not as random cracks. Proper jointing practices include locations and spacings. If joints are spaced too far apart, either out-of-joint cracking or wide joint widths will occur. Theoretically, adding water in the site to increase the concrete slump increases shrinkage. However, adding small amounts of water does not significantly increase dry shrinkage [258].

Several researchers report that extended periods of moist curing can reduce the amount of drying shrinkage by as much as 10 to 20%. However, shrinkage reductions depend on the water to cement ratios and length of moist curing[259]. For curing periods greater than four to eight days and less than 35 to 50 days, shrinkage may increase. Others report that extended curing methods only delay shrinkage and curling [260]. Therefore, it is important to consider the shrinkage potential of the concrete and slab restraints, especially the subbase friction, before selecting joint spacings.

Therefore, this real scale floor construction is mainly to evaluate the soil concrete's shrink potential by considering water content, maximum aggregate size, aggregate volume and gradation, cement type and content, and admixtures used. Then design the joint spacings.

Soil required for the floor casting was taken from the gravel pit closer to the site. The selected soil was subjected to sieve analysis and was developed to required soil compositions. Admixture, cement, and water were added according to the correct mix design. The laying of soil concrete on the floor was done in a fully manual process. The floor base was thoroughly compacted and moist before laying.

Every type of continuous "slab" flooring system, such as concrete floors, is prone to cracks. They are affected by displacement that occurs before or after drying as a result of settling, temperature changes, contraction during drying, or drying at different speeds. A few minor cracks in the floor are not inherently an indication of failure or a challenge, but rather an architectural feature that brings natural character and charm to it. Since curing is much important to ensure not only strength but also good wear resistance, proper curing was done for 28 days.

After 28 days of casting the floor was smoothening by using a terrazzo cutting machine. Then the top surface was applied clay cement plaster in two layers. In this case, as the top wash coat, the floor sealer available in the current market was used and it is used for cement rendered floor, terrazzo floor, and parquet floor too. The few steps of construction and finishing floor are shown in Figure 6-10.

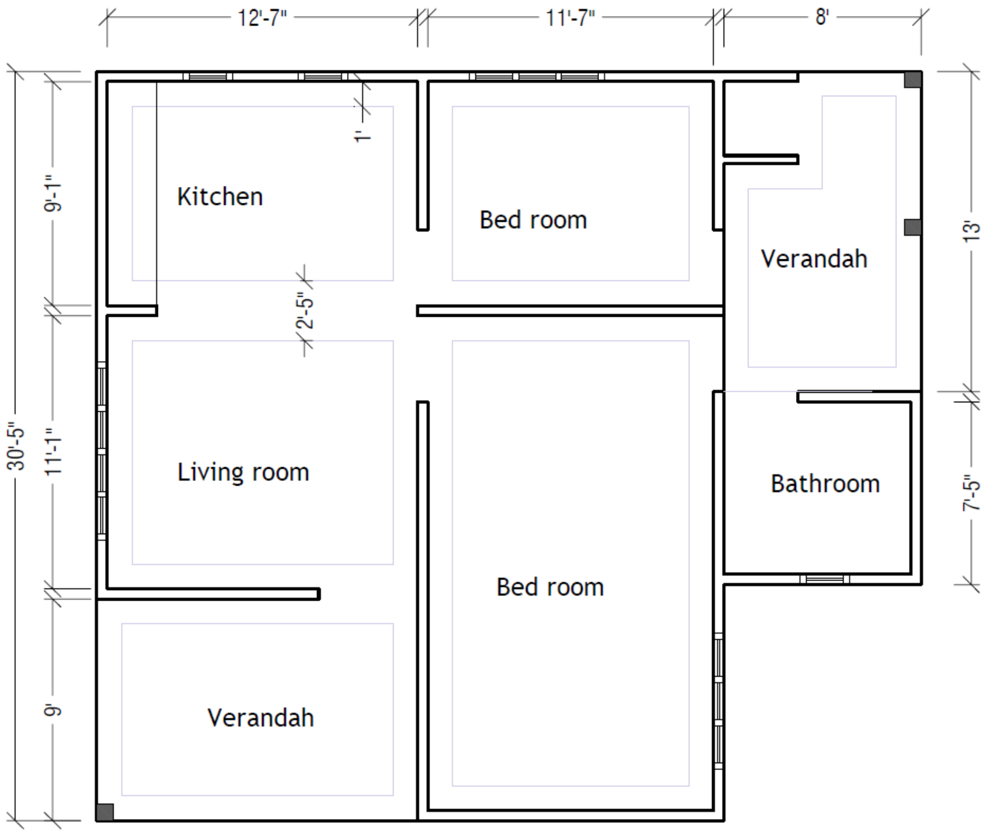



*Figure 6-9: Floor plan of selected gest house*


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*Figure 6-10: Flow diagram of casting soil concrete floor in guest house*

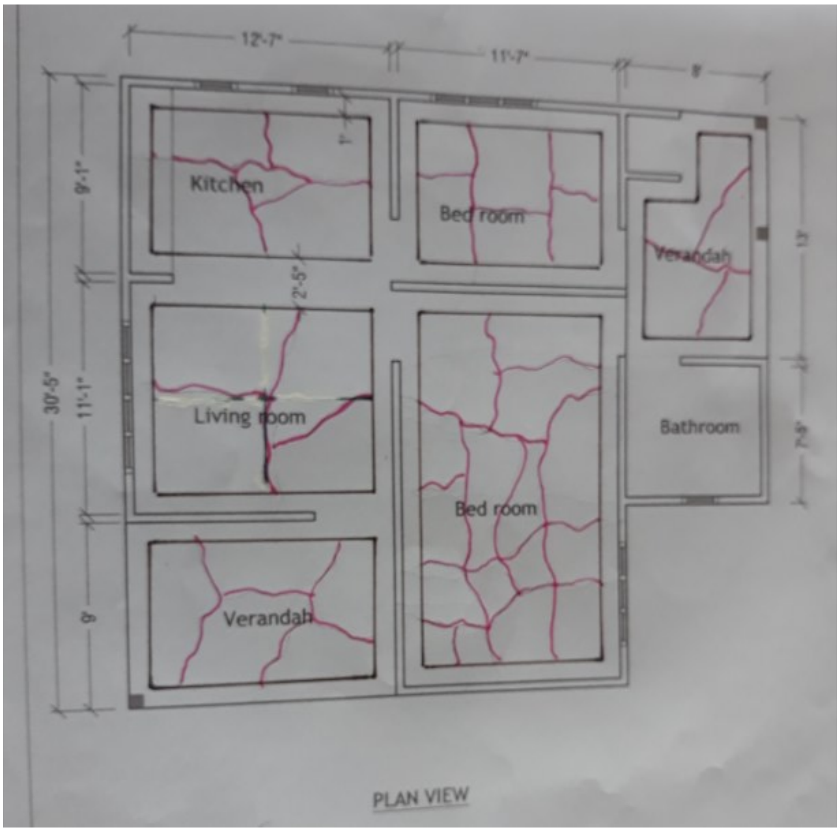


*Figure 6-11: Observed crack patterns*

Once the floor was cut using a terrazzo cutting machine small cracks were observed. The observed crack patterns are shown in Figure 6.11. According to the creak pattern, the majority of cracks have appeared in the span of 3 ft to 4 ft. Therefore, it was concluded that suitable floor spans should be provided to avoid the cracks. Glass or Aluminium strips are usually used for effective separation of panels in terrazzo flooring. In this case also, same strips were recommended. The recommended strip layout is shown in Figure 6.12.

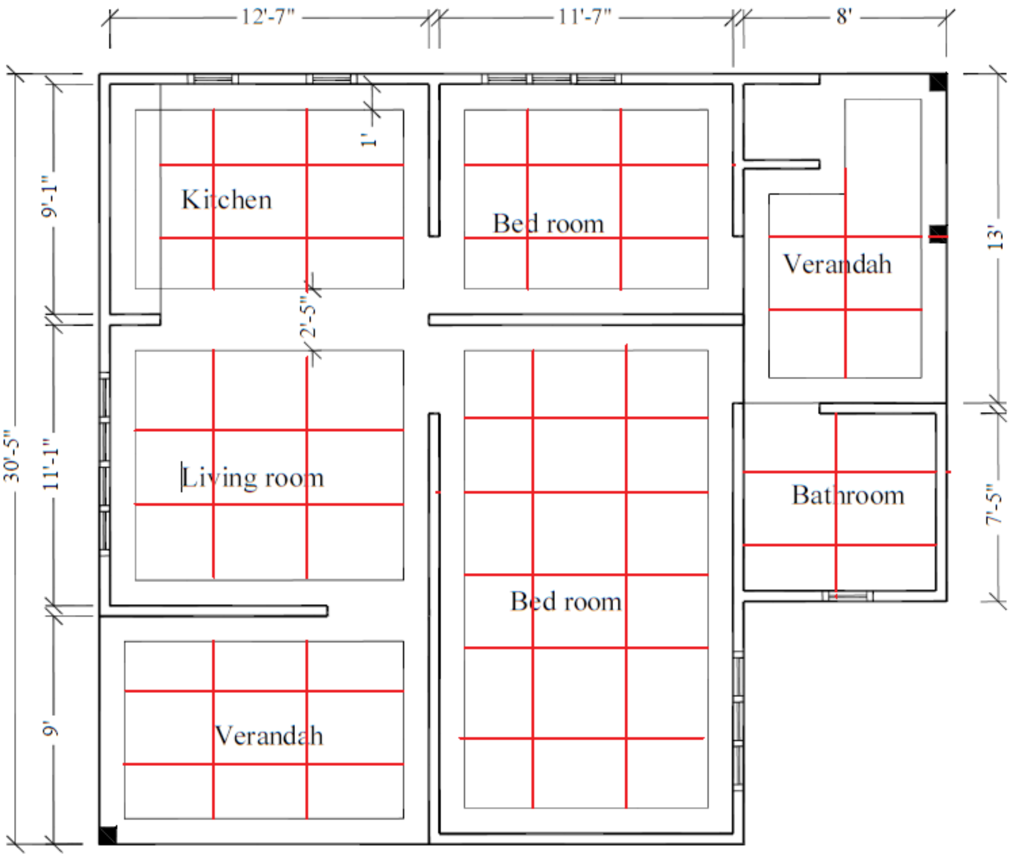


*Figure 6-12: Suggested strip patterns to avoid cracks*

## 6.4. Cost benefit analysis

Cost benefit analysis was done by calculating the Life Cycle Cost for soil concrete floor and other selected flooring materials.

### 6.4.1. Life cycle cost (LCC) Calculations

The previous chapter discussed the real scale casting done with soil flooring system which is the outcome of this research. Calculating the life cycle cost of this novel, soil flooring material is a vital factor after concluding the right mixture configuration and optimal construction technologies. As a result, this section aims to determine the true worth of the overall life-cycle cost of soil concrete, as well as to compare it to traditional flooring materials used in today's construction. Cement rendering, ceramic tile, and terrazzo are among the flooring materials used in this contrast. Using Buildings Schedule of Rates (BSR) and 2020 market values, the initial cost of the flooring materials was estimated.

The best soil concrete floor mix design was found to be 35 % of gravel (4.75mm to 25 mm), 60 % sand (0.425mm to 4.75mm), and 5% fine (less than 0.425mm) with a minimum cement content of 16%. To maintain the soil concrete floor materials in self-compacting consistency, 16% - 19% optimum water of the total dry mix is used.

The inexpensive house was given a sixty-year life cycle based on British expectations. However, since none of the chosen flooring materials have a life cycle of sixty years or more, the replacement cost of flooring materials must be factored into the LCC measurement process. Further, necessary maintenance cost also was included while calculating the total life-cycle cost of the building.

The total cost of an object over its lifetime, including preparation, construction, procurement, operations, repair, disposal, and any residual value [261] can be specified as the LCC. The amount of the construction expense and the combined sum of operating expenses, electricity costs, and other recurring costs, minus any disposal value at the end, is the net cost of both acquiring and repairing a building throughout its life (Equarion 6-1) [262], [261].

$$\boxed{LCC = Ic + (Mc + Ec + Cc + Oc) + Uc - Rv}$$

*Equation 6-1*

where,

Ic - the initial cost, Mc - maintenance costs,

Ec - the energy costs, Cc - the cleaning costs,

Oc - the overhead and management costs, Uc - the utilization costs,

Rv - the resale value

Among several methods of calculating the LCC exists, Net Present Value (NPV) method was used to calculate the LCC of this soil floor which is the most preferred LCC technique in the construction industry [263].

The net present value (NPV) of an investment is the sum of capital that must be spent now to satisfy all potential financial demands that exist over the investment's lifetime (Equation 6-2).

$$\boxed{NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t},}$$

*Equation 6-2*

Where

Ct - the estimated cost in year t,

r - the discount rate and

T - the period of analysis in years.

The following calculation takes into account the amount of interest that would be paid on the money spent. In reality, the pernicious effect of inflation will erode the value of our investment. As a result, the above formula must be modified by a factor that accounts for inflation. Inflation would raise prices in year n, resulting in a higher current investment level. The modified factor is known as the “net of inflation discount rate” (NDR) (Equation 6-3)

$$\boxed{\mathrm{NDR} = \left(\frac{1 + \mathrm{int}\%}{1 + \mathrm{inf}\%} - 1\right)}$$

*Equation 6-3*

where,

int% - the interest rate and inf% - the inflation rate.

In this calculation, LCCs are determined by subtracting the resale value from the original cost-plus repair and recovery costs. A survey of construction material manufacturers was used to collect cost information for supplies. Labour costs are determined by a leading construction firm in Colombo that is familiar with current prices. Previous scholar data were used to collect information about the life span of floor components, and Facility Managers provide forecasts of repair costs [264] [265]. [144]

In this study, LCCs were calculated on soil concrete floor as well as other flooring materials which are commonly used in Sri Lanka for the comparison purpose. In Sri Lanka, reusing building materials is primarily an informal sector practice. As a result, in practice, there are no readily accessible and credible sources of price and recyclability statistics. As a result, the reusability was only assessed in terms of potential use. Owing to their ambiguity in alternate reuses, the other alternative reuses or recycles were omitted. The assumed life times and reusability factors are tabulated in Table 6-1 [264], [266], [144]

*Table 6-1: Assumed lifetime and reusability factors*

| | Material | Life time (years) | Reusability factor (%) |
|---|---|---|---|
| 1 | Concrete | 60 | 63 |
| 2 | Cement | 60 | 0.0 |
| 3 | Wood flooring | 60 | 0.0 |
| 4 | Terrazzo flooring | 20 | 0.0 |
| 5 | Ceramic tile | 20 | 0.0 |
| 6 | Soil concrete | 60 | 100 |

The NPV is worked out on the basis of a discount rate of 5 %. During the recent past (2017–2020), the average weighted prime lending rate (AWPR) of commercial banks in Sri Lanka varied between 9.26 % and 12.24 % while the rate of inflation as measured by the Colombo District Consumer Price Index (CDCPI) varied between 6.8 % and 10.3 %. For ease of calculations we assume a uniform interest and inflation rates of 10 % thus NDR was not calculated.

The calculated LCCs for the selected flooring materials are shown in Table 6-2 and Figure 6-13 shows the comparison of the initial cost and the LCC on different available flooring materials with soil concrete floor.

*Table 6-2: Calculated LCCs for different flooring materials*

| Floor type | LCC per Sqr. (LKR) |
|---|---|
| Ceramic Tile | 42,697.00 |
| Terrazzo | 48,388.00 |
| Cement Rendered | 22,118.00 |
| Wood | 48,731.00 |
| Soil concrete | 9,904.00 |

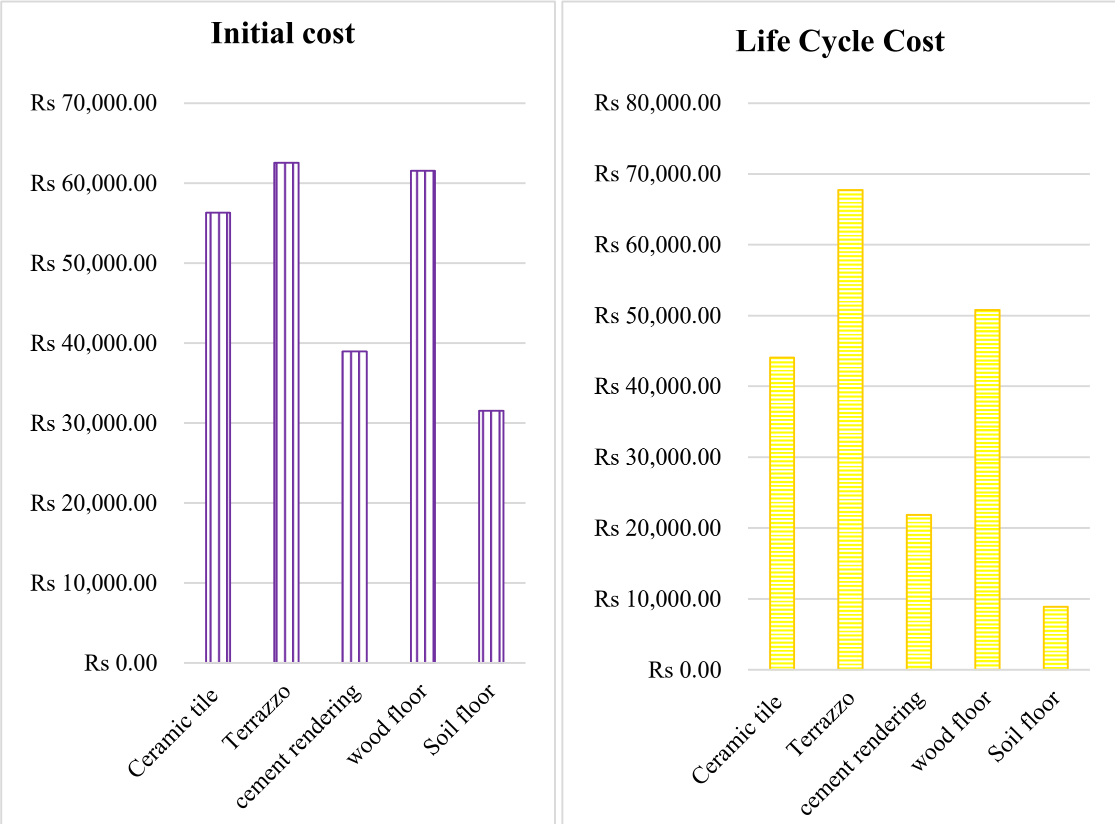


*Figure 6-13: Life Cycle Cost (LCC) and Initial cost comparison*

### 6.5. Summary

The behaviour of soil flooring on a real scale was analyzed in this chapter. For this, the two floors were cast as in a large scale and in a real scale to compare thermal performance, to determining the joint spacing needed to prevent the shrinkage cracks and to analyze the cost benefits. Thermal performance comparison results show that the temperature of the soil floor was 1 $^{0}$C lower than the temperature of other floor surfaces which was selected and the temperature of the indoor air. The need for a real-scale floor made out of soil concrete was aid in determining the joint spacing needed to prevent the shrinkage cracks. After studying the behaviour of a real-scale floor, it was determined that joint spacings should be kept to a maximum of 4 feet to minimize random fractures. It was also determined what the cost would be and how much labour would be required. With this information, the cost per square foot of floor was estimated, hence, the life cycle cost was estimated.

Then the life cycle cost with traditional flooring materials were contrasted. For the production of soil flooring, and the cost of other floorings, cost information was taken from the practice in the construction industry. The LCC is much lesser for soil concrete compared to the other common materials.

The next chapter will conclude all the processes and results obtained in this study. Recommendations for further research are also mentioned.

# CHAPTER 7 : CONCLUSION AND RECOMMENDATIONS

## 7.1. General

This chapter owed to conclude the overall work-done and results obtained throughout the research. Further, this chapter will discuss future research areas generated by the findings of this research. Building industry is currently becoming as one of the most active sector which is creating more environmental problems. Therefore, building materials and techniques are more important to convert the construction industry to sustainability. This research investigated the suitability of soil to produce flooring material. Experiments were done to find the possible means of increasing the strength of soil as the floor finishing material with the suitable mix, the thickness and the top surface finish. Then, the durability and service characteristics, cost benefits, thermal performance were evaluated. The case study also was done by casting the floor in a real scale guest house.

## 7.2. Conclusions/ Recommendations

- This research was conducted to investigate a self-compacting in-situ cast flooring material using soil. The research was mainly focused on two different sections; finding the best mix design and the suitable top coating. In addition, durability, shrinkage characteristics, thermal performance and long-term cost effectiveness including LCC were investigated.

- Theoretically, any soil type can be used in construction. However gravelly laterite soil is effective because of its easiness in making a well-graded soil sample in the mix [9]. Thus, gravelly laterite soil was chosen in entire testing procedure.

- The optimum soil gradation was first investigated to achieve the required strength of flooring material. Mix proportion was concluded with all the results obtained from the series of the experiments as fine particle content should be less than 10%, sand content should be 55%-60%, and gravel content should be

30%-35%. The maximum gravel size is 25mm for the soil concrete floor base. The required cement percentage is 18%-20% depending on the usage of admixture. Further, it was concluded that the required moisture range was 16%-19% for soil concrete without admixtures to achieve a workable mix (i.e 500 mm - 650 mm flow diameter).

- The water-cement ratio is a key parameter that governed the workability and the compressive strength of soil concrete. This study showed that the increase in water content causes a decrease in the compressive strength, linearly at a constant rate for all cement percentages. $Y=mX+C$ type of equation could be derived to convert the compressive strength for mix with any cement content and any water content value. This finding can be used in the future, to convert the experimental compressive strength value obtained in any soil concrete mix with any water content value to the compressive strength of required water content.

- The selected soil cement mix with water form a concrete and (150 x 150 x 150) mm standard test cubes were used to determine the compressive strength of this soil concrete. The best size and shape of test specimens to determine the compressive strength of soil concrete was predicted and the relationship between compressive strength and specimen size and shape on soil concrete was identified. The current study showed that the compressive strength increased with the age and more than 50% of 28 days' strength was achieved in the first 7 to 10 days and with time, strength variation showed slow increment. The compressive strength was increased with the increment of cement percentage. The rate of this increment was high for lower cement percentages and less for high cement percentages. Further, as a whole, it can be concluded that the pattern of the compressive strength variation is uniform for all the specimen shapes and sizes.

- The relationship of compressive strength of different size and shape of specimens to the compressive strength of 150 mm cubes were created. The results indicated that the effect of specimen size and shape was decreased with age. However, the 150 mm soil concrete cube's compressive strength is 0.94 times that of the 100 mm cubes and 5 times for the cylinder.

- The failure pattern of cubical and cylindrical specimens of soil concrete was compared with the failure pattern of cement concrete. During the initial stage of loading, the cracks were developed longitudinally, and when the applied load is increasing, the initial cracks were sharply propagated from top to bottom till the failure of the specimen. When increasing the load on the cubical specimens, the cracks were slowly propagated and decreased (due to the effect of shear) toward the centre of the cube. The centre core left relatively undamaged, following the 'non-explosive' failure pattern [237],[245]. According to the Authors in [237], the failure pattern of these cylindrical specimens can be defined as cone and spilled failure.

- Soil concrete was tested with the addition of metal also, but it does not influence the significant improvement of compressive strength.

- Chemical, mineral, or natural admixtures are generally used in cement concrete to improve their properties. The performance of soil concrete with admixtures was studied to reduce cement usage and for further enhancement of the soil concrete strength. The workability of soil concrete mix with admixtures showed linear variation for all types and all dosage of admixture as same as the soil concrete without admixtures but on different levels. It showed that the soil concrete workability could be improved by adding chemical admixtures but on different levels for different admixtures. Therefore, it is recommended that the use of chemical admixtures is useful to enhance the workability and strength of soil concrete. However, the dosage must be decided by doing a trial mix as per the workability requirement. These results confirm that the chemical admixtures which are used to enhance the cement concrete properties can be used to enhance the soil concrete strength too.

- The shrinkage of soil concrete also was determined according to the standard. As per the results obtained, it can be concluded that for all the water percentages the length change and weight change became zero for both drying and wetting conditions after 28 days of casting. Further, the shrinkage in both wetting and drying conditions increases with the moisture content in the soil concrete mix.

- The top surface of the soil concrete floor should have a better architectural appearance and smooth enough for user comfort. Therefore, the surfaces were smoothened in three different ways. Then the appropriate treatment for the protection of the top surface to achieve the proper service requirement was identified. The most suitable surface coating concerning sustainability without sacrificing the naturalness of soil concrete as much as possible and cost-effectiveness also were considered. Among several resins, one synthetic resin and floor sealer which is currently using for cut cement floor were selected and applied on top of prepared soil concrete floor samples. Phenol-formaldehyde novolac resin was selected and cured with the Hexamethylenetetramine (HMTA) then heat treatment was done. The resin was applied in three different ways and heart treatment was done using Liquid Petroleum (LP) gas flame.

- The bonding capacity of coating with soil concrete was determined by performing the pull off test according to the standard. Pull out failure was occurred through the soil concrete base, the fracture was not through an interface between the resin layer and soil concrete base. According to the observed failure pattern, it can be concluded that the coating layer was hardly bond to the base concrete.

- Water absorption test results showed that that water absorption was highly influenced by the top surface finishing method. The water absorption and rate of water absorption were negligible for the samples which were having top surface clay plaster and top coating. However, water absorption of the sample which was not having clay plaster but with a top coat was the next lowest and closer to that of the surface with top coats. This was concluded that the novolac resin/ floor sealer effectively provides the ability to water- repellent property to the floor. Further observations said that the water absorption property can be improved even without the clay layer effectively but cannot without top coat. The two layers of clay plaster are effective than the single clay layer. The water absorptions of samples without top coat were very much higher than that of samples with a top coat. The results also showed that the sorptivity which is one of the most important property, effectively contributes to the durability of the floor and it can be improved by selected synthetic top coat.

- According to the results of slip resistance and stain resistance it could be concluded that the soil based flooring material was within the standard requirements of durability and service characteristics. But the abrasion resistance was not satisfied for the resin application. However, the selected floor sealer which is available in the current market was showed better results than novolac with respect to the stain resistance and abrasion resistance. Therefore, finally the floor sealer was recommended for the top surface coating.

- At the end of the series of laboratory experiments, soil concrete mix proportion, and method of construction, top surface finishing material and method were decided. Then, the real scale behaviour of the proposed flooring was done. The floor in a large scale was cast first and thermal performance was evaluated to compare soil concrete with other selected existing floorings. According to the temperature variation pattern, the soil concrete floor shows lesser top surface temperature in a significant level ($1^0$C ) compared with other floorings and also indoor air temperature. Real scale floor casting concluded that the floor separator should be provided in 3 ft -4 ft intervals to prevent the surface cracks.

- Life Cycle Cost (LCC) for soil concrete floor and the selected flooring materials were calculated and it showed that the LCC is less for soil concrete in a significant level compared to other existing floorings.

- The study findings suggested that soil could be used as a flooring material and synthetic floor sealer could be used as a top surface finishing layer with long-term sustainability. Taking a walk onto an earthen floor is a great opportunity for those who often use concrete, tile, hardwood, or carpet.

- Finally, the current research was mainly focused on the development of a soil-based flooring material for tropical climates. The most important component in generating the soil concrete for the floor base is the proper gradation of soil, cement, admixture, and water in the right amounts. As a result, it's critical to pick these ingredients in the right order. The use of a 75 mm thick soil concrete floor base and a floor sealer, which is currently used in cut cement floors, as the top surface coating was recommended. Further, it is recommended to use separators at each 3 ft to 4 ft span to avoid random cracks appear on the floor.

### 7.3. Future works

Following recommendations can be made as future works which have been identified through this research study.

- The use of mineral and mechanical admixture to further improvement of strength and hence reduce the cement usage.
- Find the possibility to use natural admixtures to improve the quality of soil concrete.
- Find out the possibility to use fiber to avoid cracks development on the surface.
- Find out the way to reduce the floor thickness and hence use it as a floor finishing material for upper floors.
- Find out the way to use natural resin as the top surface coating.

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